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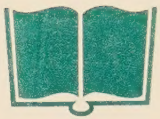

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VOLUME II

1919-1929

EDITOR

CARL O. SAUER

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UNIVERSITY OF CALIFORNIA PUBLICATIONS IN

GEOGRAPHY

VOLUME 2

1919-1928

UNIVERSITY OF CALIFORNIA PUBLICATIONS
IN
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Vol. 2, No. 1, pp. 1-18, 1 fig. in text, plates 1-2 April 3, 1919

THIRTY-YEAR SYNOPSIS

METEOROLOGICAL OBSERVATIONS MADE AT BERKELEY FROM JULY 1, 1887, TO JUNE 30, 1917

BY
BURTON M. VARNEY

With the close of the rainfall year ending June 30, 1917, the Meteorological Station at the University of California completed its thirtieth year of observations. Begun by Professor Frank Soulé in December, 1886, these observations were continued under the direction of Professor Armin O. Leuschner until the transfer of the station from the Students' Observatory to the Department of Geography, June 30, 1912. Mr. William G. Reed took charge of the work of the station at that time. The instrumental equipment was enlarged to permit of more detailed observations than had been possible before. Mr. Reed continued in charge of the station for three years and made many valuable contributions to our knowledge of the climate of Berkeley. In July, 1915, Mr. John P. Buwalda took over the direction of the station, and in his charge the work remained until the close of the thirty-year period covered by this synopsis.

On the completion of the first fifteen years of observation a synopsis of the results was published.[1] This was followed in due time by a twenty-year synopsis,[2] and later by a summary covering twenty-five years of observation.[3] This thirty-year synopsis is published in accordance with the custom of summarizing the climatic data of Berkeley at five-year intervals.

[1] *University Chronicle,* vol. 5, 1902, pp. 231–234.

[2] *University Chronicle,* vol. 10, 1908, pp. 467–473.

[3] Leuschner, A. O., Twenty-Five Year Synopsis of Meteorological Observations made at Berkeley from July 1, 1887 to June, 30, 1912, Univ. Calif. Publ. Geog., vol. 1, 1914, pp. 241–246.

CHANGES IN THERMOMETER EXPOSURE

Prior to the completion of the twenty-five year period the thermometers were exposed in a window shelter on the north side of the Students' Observatory Building. About a year before the transfer of the meteorological station to the Department of Geography a coöperative observer's shelter of the United States Weather Bureau pattern was set up on the grounds south of the observatory, and observations were begun with a duplicate set of thermometers in the new location, the window shelter observations being continued. A study of comparative readings under the two conditions of exposure was undertaken in order to determine the amount of correction to be applied to the valuable series of window shelter observations, that they might be made available for use in connection with the observations taken in the new and better location. Day-by-day results of this comparison are unfortunately not available in sufficient numbers to permit a detailed study of the amounts of the differences. It was necessary for the purposes of this thirty-year synopsis, however, to determine these differences as accurately as possible.

Inspection of the data at hand indicates that different weather conditions have had different effects on the readings in the two locations, sometimes causing them to show only slight differences, at other times greater differences, and that at isolated and irregular times individual differences have been considerably in excess of the average. It is clear that such excessive departures may exert an undue influence on the means of the departures. Being irregular and often widely separated in point of time they do not tend to neutralize each other. A large difference, occurring only once in a month and hence by no means typical of average conditions, may cause the mean difference to appear excessive. In other words, the arithmetical mean of all the differences may not be the most probable difference.

During the years (by rainfall seasons, July 1 to June 30) 1912–13 to 1915–16 observations were made in both the new and the old locations. Among other data, mean monthly, mean daily maximum and mean daily minimum temperatures were computed for both locations, and were published regularly in the monthly *Meteorological Synopsis of Berkeley*. These means, representing four consecutive

TABLE I.—COMPARISON OF TEMPERATURES OBSERVED UNDER DIFFERENT CONDITIONS OF EXPOSURE AT THE METEOROLOGICAL STATION, UNIVERSITY OF CALIFORNIA.

(Plus and minus signs show respectively the number of degrees F. by which temperatures in the new location exceeded or fell below those in the old).

	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June	Year
Mean differences between mean daily maximum temperatures	+3.2	+3.0	+4.2	+6.2	+3.4	+3.0	+3.4	+4.1	+4.8	+2.4	+1.3	+2.5	+3.5
Mean differences between mean daily minimum temperatures	—2.0	—1.8	—1.2	—0.7	—1.2	—0.6	—0.6	—0.6	—0.3	—1.4	—0.7	—2.0	—1.1
Mean differences between monthly mean temperatures	+0.6	+0.7	+1.5	+2.8	+1.5	+1.2	+1.4	+1.9	+2.3	+0.5	+0.4	+0.2	+1.3

TABLE II.—EXAMPLE OF CORRECTION FOR CHANGE OF EXPOSURE FOR THE CASE OF THE MEAN DAILY MAXIMUM TEMPERATURE.

	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June
Twenty-five-year means, old exposure	70.1	69.1	69.7	67.2	61.1	54.5	53.4	56.8	58.8	63.1	66.2	70.5
Mean differences between mean daily maxima	3.2	3.0	4.2	6.2	3.4	3.0	3.4	4.1	4.8	2.4	1.3	2.5
Corrected twenty-five-year means	73.3	72.1	73.9	73.4	64.5	57.5	56.8	60.9	63.6	65.5	67.5	73.0

years of comparative readings, have been used for reducing the temperatures obtained in the window shelter to make them as nearly comparable as possible to those obtained in the new location. This has been done partly because of the absence of more complete data and partly because it is impracticable to begin a new series of comparative readings at this time. The results herewith are presented with full recognition of the fact that, as pointed out above, a mean difference between the two sets of temperatures is not the most desirable basis for comparison.

Certain considerations, however, lead to the assumption that the reduction by this method in this case gives results correct to within a fraction of a degree. It will be seen from table 1 that the mean differences by months show the mean daily maximum temperature in the coöperative observer's shelter for every month to be higher than the mean daily maximum in the window shelter, and the mean daily minimum for every month to be lower in the coöperative shelter. The mean monthly differences between the maxima are consistently greater than those between the minima. Neither set of differences shows any erratic, excessive values.

In the computation of the thirty-year means, therefore, the values of the monthly means and of the mean daily maximum and mean daily minimum temperatures for the twenty-five year period have been corrected by the amounts of the average differences, shown in table 1, before being incorporated in the thirty-year means. Wherever maximum temperatures have been involved the differences in the mean daily maxima have been used for correction. Where minimum temperatures were involved the differences in the mean daily minima were used. Where temperature ranges were under correction the arithmetical sums of the difference between the mean daily maxima in the two locations plus the difference between the mean daily minima were used. Table 2 illustrates the general method, using the case of the mean daily maximum temperatures as an example. In the explanation of the thirty-year averages, which are set out in tables 3 and 4 following, the method of correcting each item is described in detail.

The thirty-year averages, which in every case are the arithmetical means of the data involved, appear in English units in table 3 and in absolute units in table 4. In some cases the data used for computing certain values are no longer used for that purpose by the Weather Bureau and the practice of this station has been changed to

accord with the present accepted usage. Such cases are noted in the explanation and comments on the tables.

Much of the tedious work of reducing the old means and computing the new has been done by Miss Florence F. Ingram, to whom the writer is indebted for very great assistance.

EXPLANATION OF TABLES 3 AND 4

Atmospheric Pressure

1. *Monthly mean.*—This is the mean of the daily average pressures, which were found by dividing the sum of the pressures at each observation hour (corrected and reduced to sea level) by the number of observation hours. The station practice has not until recently included the reduction of the daily averages so obtained to the true daily mean.

2. *Monthly mean maximum.*—Found by dividing by thirty the sum of the highest pressures (reduced to sea level) for any given month for thirty years. This value is probably somewhat inaccurate, as previous to September, 1913, no account of pressures other than at the regular observation hours was kept. Since that date, the absolute highest pressure has been taken from the barograph, whatever time in the month it occurred, corrected, and reduced to sea level equivalent.

3. *Monthly mean minimum.*—Computed similarly to (2) above, using lowest monthly pressures.

4. *Monthly mean range.*—Found by dividing by thirty the sum of the differences between the monthly mean maxima and minima for any given month for thirty years. These values are subject to the same inaccuracy noted under (2) above.

5. *Mean highest daily average.*—Found by dividing by twenty-five the sum of the highest mean daily pressures in a given month for twenty-five years. The average pressure for each day was found as indicated under (1) above. These means are for the twenty-five year period, 1887–1912 only, and are taken from the twenty-five year synopsis.[4] The daily averages of pressure are no longer computed.

6. *Lowest daily average.*—See comments under (5) above.

[4] *Loc. cit.*, p. 1.

Air Temperature

7. *Monthly mean.*—Previous to July, 1912, this value was based on daily mean temperatures which were found by dividing the sums of the temperatures at each observation hour by the number of observations. Since the above date, following the practice of the United States Weather Bureau, the daily mean has been taken as the average between the maximum and minimum temperatures for the day. The daily means based on ½(max. + min.) had been computed throughout the twenty-five year period, but had not been used as a basis for the published monthly means. In preparing the thirty-year means the daily means so computed have been used. Before incorporating the twenty-five year means in the present tables they were raised for each month by the amount of the monthly mean difference in temperature as observed in the old and new locations, as set out in table 1.

8. *Daily maximum.*—This is the average of the highest temperatures of each day for each month. The twenty-five year means were raised by the amount of the monthly mean differences between the maximum temperatures in the two locations (table 1), before incorporation in the thirty-year means.

9. *Daily minimum.*—Computed similarly to (8) above, using the average lowest daily temperatures, and reducing the twenty-five year means by the amount of the monthly mean difference between minima.

10. *Daily range.*—Found by dividing by thirty the sums of the differences between the mean daily maxima and minima for each month. In the correction of the twenty-five year mean daily ranges, the arithmetical sums of the differences between the mean maxima in the old and new locations plus the differences between the mean minima have been added to the twenty-five year averages for each month:

July mean daily range, twenty-five years	16.6
July mean difference in daily maxima	3.2
July mean difference in daily minima	2.0
Corrected mean daily range, twenty-five years	21.8

11. *Greatest daily range.*—The twenty-five year ranges have been corrected in the same manner as the mean daily ranges in (10), and the thirty-year means computed from the sums of the greatest daily ranges for each month in the period.

12. *Least daily range.*—Treated in every respect like the mean of the greatest daily ranges.

13. *Absolute monthly maximum.*—These are averages of the highest temperatures observed in each month during the thirty years, the twenty-five year means having been corrected for change of exposure by adding the monthly average differences between maxima as before.

14. *Absolute monthly minimum.*—Computed by the same method as the means in 13.

15. *Absolute monthly range.*—This is the average of the differences between the mean absolute monthly maxima and minima for each month.

16. *Highest daily average.*—Found by dividing by thirty the sums of the average temperatures of the warmest day in each month. The twenty-five year means were first raised by the amount of the average differences between the means from the two exposures, for each month.

17. *Lowest daily average.*—Treated similarly to (16) above.

18. *Diurnal variability.*—The average difference between the mean temperatures of consecutive days—the mean based on $\frac{1}{2}$(max. + min.)—both increase and decrease of temperature from one day to the next being considered merely as so much change.

Precipitation

19. *Monthly precipitation.*—This includes rainfall, dew, and fog, and also water-equivalent of snow on the extremely rare occasions of the occurrence of snow at this station. The precipitation at Berkeley, being under the subtropical régime of rainfall, with a pronounced wet and dry season, is subject to considerable monthly and annual variation. For this reason it is likely that the arithmetical means here given do not express the "normal" precipitation for each month in the sense that the given amount is the most probable amount. In a region the rainfall of which may fairly be called erratic the thirty-year period of observation is inadequate for the computation of a reliable series of monthly normals.

20. *Monthly precipitation: Percentage of seasonal total.*—These per cents indicate, perhaps more clearly than the actual monthly amounts, each month's average share of the total yearly precipitation.

21. *Monthly accumulated precipitation.*—This is the average total precipitation recorded between the beginning of the rainfall year (July 1) and the end of any given month.

22. *Monthly accumulated precipitation; percentage of seasonal total.*—These values indicate that from the beginning of the rainfall season to the end of any month there will have been recorded on an average the stated percentage of the mean seasonal total precipitation.

Relative Humidity and Temperature of the Dew Point

23. *Relative humidity, 8 a.m.*—Stated in per cents, 100 per cent indicating saturation. The indications of the ordinary hygrograph are not strictly accurate, hence no record is kept of relative humidity maxima, minima, or ranges. The means are based on records covering twenty-five years to June 30, 1917.

24. *Relative humidity, 8 p.m.*—See (23) above.

25. *Monthly relative humidity.*—Based on ½(8 A.M. + 8 P.M. rel. hum.).

26. *Temperature of the dew point at 8 a.m.*

27. *Temperature of the dew point at 8 p.m.*

Weather

28. *Cloudiness at 8 a.m.*—These values are expressed in the number of tenths of the sky covered by cloud at the time of observation. They are based on estimates by individual observers and hence do not purport to give more than a general indication of the morning and evening cloudiness conditions at Berkeley. The averages are for twenty-five years, including 1916–17.

29. *Cloudiness at 8 p.m.*—See note on (28) above.

30. *Number of clear days.*—Close observation of the state of the sky except at the regular observation hours has not been practicable, therefore the figures showing the average numbers of *clear days*, and of *partly cloudy days* (line 31) and of *cloudy days* (line 32) are subject to some doubt. It is probable, however, that after thirty years of observation, individual estimates of the general character of the cloudiness conditions are reasonably well averaged. The classification has been made on the basis of a "clear" sky being one which is three-tenths cloud covered or less, a "partly cloudy" sky one cloud covered up to seven-tenths, and a "cloudy" sky one which is eight-tenths cloud covered and over.

33. *Number of days with fog.*—A true fog is so regarded only when the observer is in it. The "high fog" (velo cloud), which at

Berkeley during the summer months frequently covers the sky from late in the afternoon to some time in the following forenoon, is treated in the records of the station in every respect like a cloud, no matter if it hangs but a very few hundred feet above the ground. At times, however, the velo cloud touches the ground about the instrument shelter, and is then recorded as fog, no distinction being made in the record between it and radiation fog. The greater amounts of summer fog shown in the table are due principally to the low-lying velo cloud; the lesser amounts of winter fog are due to the much rarer occurrence of fog of the radiation type.

34. *Number of days with frost.*—It is probable that the values here given show less than the true number of frosts occurring on the Campus. The area about the instrument shelter has excellent air drainage toward the lower parts of the University grounds, making the formation of frost near the shelter rather less frequent than it would otherwise be. The figures in the table may therefore be taken to indicate approximately the average frequency of *heavy* frosts over the major portion of the Campus.

35. *Number of days with rain.*—A day with rain, in the station usage, is a day on which .01 inch (.25 mm.) of precipitation is recorded, the rainfall day beginning and ending at 8 P.M. local time. For July and August, months of such scant rainfall that a thirty-year mean would indicate less than one day, the total number of days is given on which precipitation has occurred within the period of record.

Wind Direction

36. *Prevailing wind direction.*—The station has not been equipped with a wind vane, hence the daily estimates of wind direction have been made by eye observation, on the motion of smoke, flags, trees or low clouds. For this reason it has not been possible to compute resultant wind directions. The figures in the table represent the most common direction for each month as estimated from twenty-five year totals (period ending June 30, 1917) for winds recorded to eight points of the compass. When more than one direction is given the first is that of greatest frequency. At this station the preponderance of winds from the stated directions over those from other directions is so marked that in the absence of complete wind data the present method of summarizing gives a reasonably true picture of conditions.

TABLE III.—METEOROLOGICAL OBSERVATIONS—THIRTY YEAR MEANS, FOR THE PERIOD JULY 1, 1887 TO JUNE 30,1917. (English Units).

(Seasonal totals in heavy type)

	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June	Seasonal Means & Totals
Atmospheric Pressure (Inches)													
1 Monthly mean	29.943	29.941	29.946	30.002	30.080	30.115	30.085	30.067	30.044	30.026	29 970	29.949	30.014
2 Monthly mean maximum	30.098	30.093	30.104	30.219	30.312	30 427	30.390	30.388	30.346	30.269	30.204	30.140	30.249
3 Monthly mean minimum	29.769	29.782	29.714	29.738	29.741	29.720	29.608	29.653	29.635	29.759	29.721	29 735	29.715
4 Monthly mean range	.329	.311	.390	.481	.571	.707	.782	.735	.711	.510	.483	.405	.534
5 Highest daily average	30.072	30.054	30.069	30.147	30.262	30 388	30.338	30.326	30.288	30.242	30.161	30.101	
6 Lowest daily average	29.805	29.803	29.770	29.779	29.814	29.792	29.703	29.732	29.683	29.799	29.786	29.776	
Air Temperature (Degrees F.)													
7 Monthly mean	62.3	62.3	63.5	62.1	55.4	49.7	48.8	52.2	54.3	55.9	58.0	61 4	57.1
8 Daily maximum	72.9	72.2	74.0	73.0	64.2	57.1	56.3	60.8	63.7	65.8	67.3	72.6	66 6
9 Daily minimum	51.7	52.5	53.0	51 2	46.5	42.2	41.3	43.6	44.9	45.9	48.7	50 2	47 6
10 Daily range	21.2	19.7	21.0	21.8	17.7	14.9	15.0	17.2	18 7	19.9	18.6	22.4	19.0
11 Greatest daily range	33.1	31.9	34.4	34.9	26.2	22.6	22.2	24.7	28 2	30.7	30.9	33.2	29 4
12 Least daily range	12.6	12.0	11.5	12.0	9.5	9.0	8.1	8.9	10 3	10.2	8.6	12.1	10 4
13 Absolute monthly maximum	86.7	84.6	89.7	89.1	74.6	65.2	64.3	70.2	76 2	79.2	82.8	87.1	79 1
14 Absolute monthly minimum	48.0	49.0	48.0	45.0	38.9	34.3	33.3	34.9	37 4	39.1	42.8	45.1	41 3
15 Absolute monthly range	38.7	35.6	41.7	44.1	35.7	30.9	31.0	35.3	38.8	40.1	40.0	42.0	37 8
16 Highest daily average	68.3	66.9	70.0	70.6	63.0	57.0	55.8	58.3	61.8	62.6	66.0	68 4	64.1
17 Lowest daily average	55.8	56.6	56.3	54.2	47.7	41.6	40.7	43.3	45.3	48.2	51.3	54 0	49.6
18 Diurnal variability	2.0	1.8	2.4	2.7	2.2	2.2	2.2	2.3	2 2	2.2	2.3	2.6	2.26
Precipitation (Inches).													
19 Monthly precipitation	0.03	0.06	0.57	1.33	2.54	4.43	6.23	4.22	4 39	1.36	1.19	0.20	**26.55**
20 Percentage of seasonal total	0.1	0.2	2.3	5.0	9.6	16.7	23.5	15.9	16.0	5.1	4.5	1 0	100%
21 Monthly accumulated precipitation	0.03	0.09	0.66	1.99	4.53	8.96	15.19	19.41	23.80	25.16	26.35	26 55	**26 55**
22 Percentage of seasonal total	0.1	0.3	2.5	7.5	17.1	33.7	57.2	73.1	89.6	94.8	99.2	100 0	100%
Relative Humidity and Temperature of the Dew Point													
23 Relative humidity, 8 a.m.	87%	88%	86%	86%	86%	87%	90%	86%	87%	85%	84%	83%	86%
24 Relative humidity, 8 p.m.	85%	87%	85%	81%	83%	85%	83%	86%	87%	86%	86%	85%	85%
25 Monthly relative humidity	86%	88%	86%	85%	81%	86%	87%	86%	87%	85%	85%	84%	86%
26 Temperature of the dew point, 8 a.m.	54.1	55.0	53.9	51.4	46.5	41.8	41.6	43.0	44 7	47 8	51.1	52 9	48 6
27 Temperature of the dewpoint, 8 p.m.	55.6	55.9	55.0	52.8	48.4	43.7	43.5	45.9	46.5	48.9	51.1	54.3	50.1
Weather													
28 Cloudiness at 8 a.m.	.6	.7	.5	.4	.5	.4	.6	.5	.6	.5	.5	5	.5
29 Cloudiness at 8 p.m.	.5	.6	.4	.3	.4	.4	.4	.2	.4	.4	.4	4	.4
30 Number of clear days	13	10	13	15	15	14	11	12	12	14	13	16	**158**
31 Number of partly cloudy days	7	9	8	8	6	7	8	6	7	8	8	7	**89**
32 Number of cloudy days	11	12	9	8	9	10	12	10	12	8	10	7	**118**
33 Number of days with fog	11	11	7	4	4	2	2	3	2	2	2	5	**55**
34 Number of days with frost	0	0	0	0	4	8	8	4	3	12 in 27 years	0	0	**27**
35 Number of days with rain	11 in 30 years	12 in 30 years	3	5	7	10	14	9	10	6	5	1	**71**
Wind Directions													
36 Prevailing wind direction	SW	SSW	SW	S	S	SE and N	S and SE	S and SE	SSW and N.	SSW	SW	SSW	

TABLE IV.—METEOROLOGICAL OBSERVATIONS—THIRTY YEAR MEANS, FOR THE PERIOD JULY 1, 1887 TO JUNE 30, 1917. (Absolute units.)

	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	April	May	June	Seasonal
Atmospheric Pressure (Millibars)													
1 Monthly mean	1013.9	1013.8	1014.0	1015.8	1018.6	1019.7	1018.7	1018.2	1017.3	1016.8	1014.8	1013.2	1016.4
2 Monthly mean maximum	1019.3	1019.0	1019.4	1023.3	1026.5	1030.5	1029.2	1029.1	1027.7	1024.9	1022.8	1020.6	1024.3
3 Monthly mean minimum	1008.1	1008.6	1006.2	1006.8	1007.1	1005.4	1002.5	1004.2	1003.5	1007.8	1005.4	1005.9	1006.2
4 Monthly mean range	11.2	10.4	13.2	17.3	19.4	25.1	26.7	24.9	24.2	17.1	17.4	14.7	18.1
5 Mean highest daily average	1918.3	1017.7	1018.3	1020.9	1024.7	1029.1	1027.4	1027.0	1025.5	1024.1	1021.3	1019.3	.....
6 Mean lowest daily average	1008.3	1008.2	1008.1	1008.5	1009.6	1008.9	1005.8	1006.8	1005.1	1009.1	1008.7	1008.3	.....
Air Temperature (Degrees Absolute).													
7 Monthly mean	289.8	289.8	290.5	289.7	286.0	282.8	282.3	284.2	285.4	286.3	287.4	289.3	286.9
8 Daily maximum	295.7	295.3	296.3	295.8	290.9	286.9	286.5	289.0	290.6	291.8	292.6	295.6	292.2
9 Daily minimum	283.9	284.4	284.7	283.7	281.1	278.7	278.2	279.4	280.2	280.7	282.3	283.1	281.7
10 Daily range	11.8	10.9	11.6	12.1	9.8	8.2	8.3	9.6	10.4	11.1	10.3	12.5	10.5
11 Greatest daily range	18.4	17.7	19.1	19.4	14.6	12.5	12.3	13.7	15.7	17.1	17.2	18.4	16.3
12 Least daily range	7.0	6.7	6.4	6.7	5.3	5.0	4.5	4.9	5.7	5.7	4.8	6.7	5.8
13 Absolute monthly maximum	303.4	303.2	305.1	304.7	296.7	291.4	290.9	294.2	297.6	299.2	301.2	303.6	299.2
14 Absolute monthly minimum	281.9	282.4	281.9	280.2	276.8	274.3	273.7	274.6	276.0	276.9	279.0	280.3	278.2
15 Absolute monthly range	21.5	9.9	23.2	24.5	19.9	17.1	17.2	19.6	21.6	22.3	22.2	23.3	21.0
16 Highest daily average	293.2	292.4	294.1	294.4	290.2	286.9	286.2	287.6	289.6	290.0	291.9	293.2	290.8
17 Lowest daily average	286.2	286.7	286.5	285.3	281.7	278.3	277.8	279.3	280.4	282.0	283.7	285.2	282.8
18 Diurnal variability	1.1	1.0	1.3	1.5	1.2	1.2	1.2	1.3	1.2	1.2	1.3	1.4	1.25
Precipitation (Millimeters).													
19 Monthly precipitation	0.76	1.52	14.48	13.78	64.52	112.52	158.24	107.19	111.51	34.54	30.23	5.08	674.37
20 Percentage of seasonal total	0.1	0.2	2.3	5.0	9.6	16.7	23.5	15.9	16.0	5.1	4.5	1.0	100%
21 Monthly accumulated precipitation	0.76	2.29	16.76	50.55	115.06	227.58	385.83	493.01	604.52	639.07	669.29	674.37	674.37
22 Percentage of seasonal total	0.1	0.3	2.5	7.5	17.1	33.7	57.2	73.1	89.6	94.8	99.2	100.0	100%
Temperature of the Dew-Point (Degrees absolute).													
26 Temperature of the dewpoint, 8 a.m.	285.3	285.8	285.2	283.8	281.1	278.4	278.3	279.1	280.1	281.8	283.6	284.6	282.2
26 Temperature of the dewpoint, 8 p.m.	286.1	286.3	285.8	284.6	282.1	279.5	279.4	280.7	281.1	282.4	283.6	285.4	283.1

EXTREMES OF PRESSURE, TEMPERATURE, AND RAINFALL

In a climate in which the changes of temperature and pressure are moderate and the variability of the rainfall great, some interest attaches to the matter of the recorded extremes of these elements. Table 5 shows certain of these extremes observed in the thirty years under review, together with the dates of their occurrence for all except the daily ranges of temperature.

Notable extremes.—Atmospheric pressure at Berkeley rarely reaches, even in winter, very low values. Only in the months of January and February has it fallen to or below 29.20 inches, and only in January below 29.00 inches. The low pressure of January 27, 1916, which for this station was extraordinarily low, 28.97 inches, was reached when the center of a cyclonic depression of marked intensity passed over central California. The barograph trace for that day

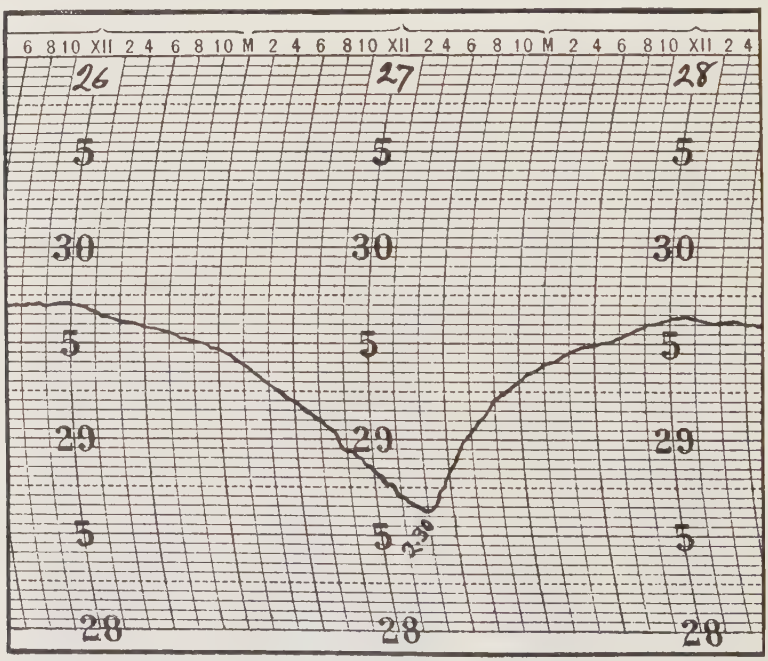

Fig. 1. Barograph curve of January 26–28, 1916, Meteorological Station, University of California. The lowest pressure as indicated was for the value at the height of the instrument above sea level, approximately 323 feet. The sea level equivalent was 28.97 inches.

showed the characteristics of pressure conditions near the center of moderate tropical hurricanes rather than those of the usual extra-tropical cyclone. High winds and a sudden shift of wind from southerly to northwesterly direction accompanied the passage of this cyclone over Berkeley.

Among the temperature extremes it is noticeable that but two months of the year have shown maximum temperatures over 100° F., September 16, 1913, having 105.5° and June 6, 1903, having 101.1°. In six out of the twelve months the temperature has reached 90° and over, and only December, January and February have had temperatures below freezing.

The precipitation figures of table 5 give some hint of the extreme variability of the Berkeley rainfall. The same month, January, which in 1910 had almost sixteen inches of rainfall (the heaviest monthly rainfall recorded at this station and well over half of the average seasonal total precipitation), had in 1889 but three-quarters of an inch. Seven months out of the twelve have at some time during the thirty years been rainless. Only December, January, February, March, and April have never failed to record some precipitation, and of these December is the only month that has never recorded less than one inch.

TABLE V.—EXTREMES RECORDED DURING THIRTY YEARS ENDING JUNE 30, 1917.

	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June
Atmospheric Pressure (Sea-level equivalents).												
Maximum	30.22	30.19	30.20	30.39	30.49	30.83	30.58	**30.90**	30.69	30.45	30.31	30.22
Date	12, 1888	26, 1916	26, 1894	24, 1916	13, 1895	25, 1903	7, 1913	1, 1916	6, 1916	15, 1895	21, 1893	4, 1894
Minimum	29.58	29.56	29.43	29.47	29.30	29.39	**28.97**	29.20	29.23	29.23	29.58	29 48
Date	19, 1893	4, 1893	13, 1913	20, 1889	18, 1913	24, 1916	27, 1916	2, 1891	8, 1891	28, 1901	25, 1906	3, 1893
Air Temperature.												
Maximum daily average	79.2	81.7	**86.8**	78.5	73.8	61.0	69.6	69.0	74.6	72.4	77.6	83.3
Date	2, 1903	26, 1894	16, 1913	8, 1899	16, 1895	18, 1893	26, 1899	18, 1899	17, 1914	12, 1898	26. 1898	29, 1891
Minimum daily average	54.0	54.0	53.0	49.2	46.7	38.5	**32.4**	35.6	39.1	44.6	49 5	50 7
Date	18, 1903	6, 1887	3, 1903	23, 1899	13, 1916	16, 1915	15, 1888	14, 1899	3, 1896	19, 1896	15, 1894	6, 1914
Absolute maximum	97.3	93.4	**105.5**	95.4	82.0	69.6	77.0	79.5	87.1	86.6	92.5	101.1
Date	7, 1905	22, 1891	16, 1913	1, 1913	16, 1895	24, 1901	26, 1899	18, 1899	17, 1914	24, 1913	26, 1896	6, 1903
Absolute minimum	42.3	46.4	45.9	39.3	33.0	30.0	24.9	**24.2**	33.9	36.0	39.9	42.4
Date	29, 1899	31, 1905	28, 1905	18, 1905	28, 1895	31, 1915	14, 1888	12, 1905	30, 1905	19,1896	1, 1899	2, 1903
Maximum daily range	36.8	36.0	**42.0**	38.5	32.5	35.5	27.7	25.4	36.0	37.0	34.8	34.8
Minimum daily range	2.9	5.0	3.2	2.6	2.0	3.2	2.2	**1.5**	2.3	2.1	3.4	4.8
Precipitation.												
Maximum monthly	0.44	0.90	4.44	5.80	5.89	12.63	**15.99**	10.68	13 19	6.72	3.43	1.24
Year	1891	1896	1904	1889	1903	1894	1910	1891	1899	1896	1905	1907
Minimum monthly	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	1.22	0.78	0.36	0.31	0.02	**0.00**	**0.00**
Year	19 in 30	20 in 30	7 in 30	3 in 30	1890	1898	1889	1896	1898	1909	1909	10 in 30
Maximum in 24 hours	0.44	0.84	1.04	3.70	**2.47**	3.24	4.10	**4.75**	3.43	2.48	2.16	0.63
Date	9, 1891	29, 1896	28, 1901	20, 1899	20, 1903	13, 1915	2, 3, 1916	**12, 1904**	13, 1899	24, 1896	1, 1905	17, 1894
Maximum seasonal total	**46.00**	1889-90,										
Minimum seasonal total	**14.40**	1897-98,										

Note on Temperature and Rainfall Graphs

The temperature and rainfall graphs in plates 1 and 2 have been drawn in accordance with the practice of beginning the meteorological year on July 1 at this station. This corresponds to the subtropical rainfall season having a midwinter maximum of precipitation.

Figure 1 of plate 1 shows the monthly mean temperatures plotted from the data in line 7 of tables 3 and 4. The curve is characteristic of the temperature régime under subtropical conditions on a windward continental coast. The mean annual range of temperature is only 14.7°, and the summer maximum which at stations in continental interiors occurs almost always in July is delayed until September at Berkeley. Figures 2 and 3 of the same plate should be read together. In figure 2 are plotted the mean daily maximum and minimum temperatures. The curves show a very moderate difference in both maxima and minima between the warmest and the coldest months, though the maxima show somewhat more change than the minima. An important result of the latter condition is shown in figure 3, which indicates the mean daily range of temperature. This range is never extreme and shows very little change throughout the year. October and June are shown to be the months of greatest daily ranges; December and January the months of least range. The curve in figure 4 indicates the diurnal variability for each month. This value is a good index of the lack of changeableness in the Berkeley temperatures, the mean change from day to day reaching a maximum of only 2.7° in October, and being extraordinarily uniform throughout the year. The curve, read in connection with that showing the mean daily range, serves better than any of the others to emphasize the equability of the climate at this station.

The rainfall graphs in plate 2 indicate the subtropical rainfall control, June, July, and August being practically rainless, while December, January, February and March contribute close to three-quarters (actually 72.1 per cent) of the seasonal total. Figure 2 of plate 2 is an attempt to combine in graphic form the representation of the monthly accumulated precipitation with an indication of the relative importance of the various months in adding to the amount of precipitation already recorded.

Transmitted October 1, 1918.

PLATE 1

Fig. 1. Monthly mean temperatures at the meteorological station, University of California, based on thirty years of observation for the period ending June 30, 1917. Note the relatively rapid change from summer to winter temperature conditions, as compared to the change from winter to summer, due to the delayed maximum falling in September-October and the minimum in December-January.

Fig. 2. Mean daily maximum and mean daily minimum temperatures for each month. Note the tendency of the daily minima to vary from month to month somewhat less than the daily maxima (see fig. 3).

Fig. 3. Mean daily range of temperature for each month, showing the effect of the different rates of change of maxima and minima from month to month. Note that, broadly speaking, the months of greatest ranges are also the months of highest temperatures, and those of smallest ranges also those of lowest temperatures.

Fig. 4. Mean diurnal variability for each month. Note that the only important deviation from the uniform average differences in the mean temperatures of consecutive days occurs in the months of greatest range and highest temperatures.

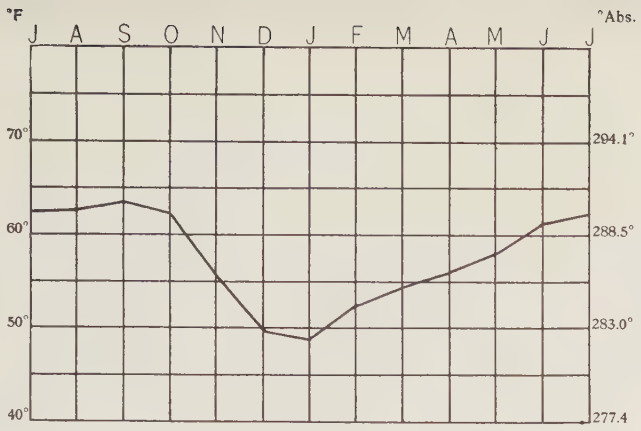

Fig. 1

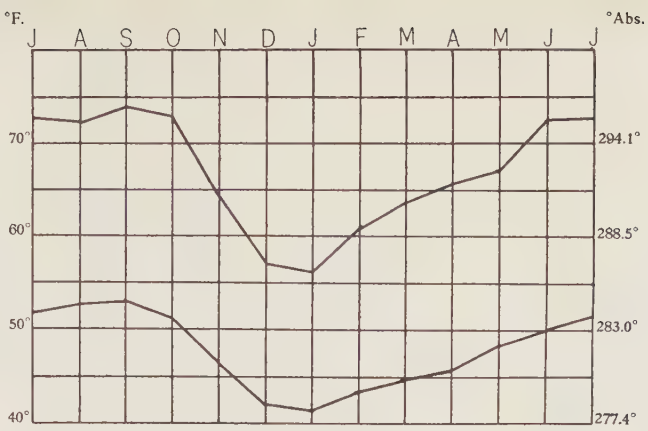

Fig. 2

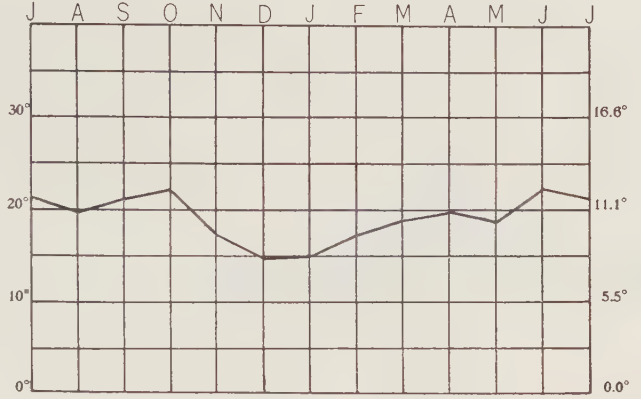

Fig. 3

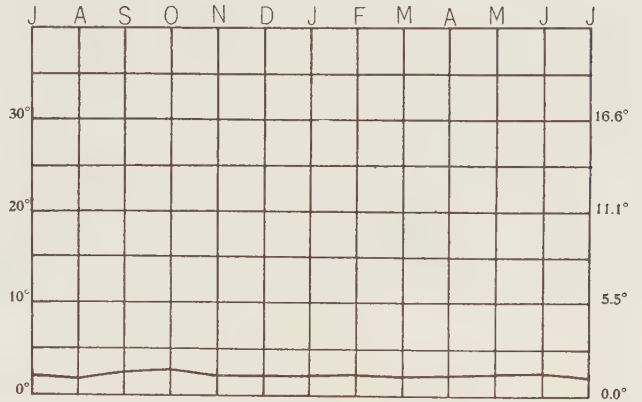

Fig. 4

PLATE 2

Fig. 1. Monthly mean precipitation. Note the tendency to a secondary maximum of rainfall in March.

Fig. 2. Monthly mean accumulated precipitation. The white lower portion of the columns indicates the amount of precipitation recorded to the end of the preceding month, the black upper portion each month's normal contribution to the seasonal total to the end of that month.

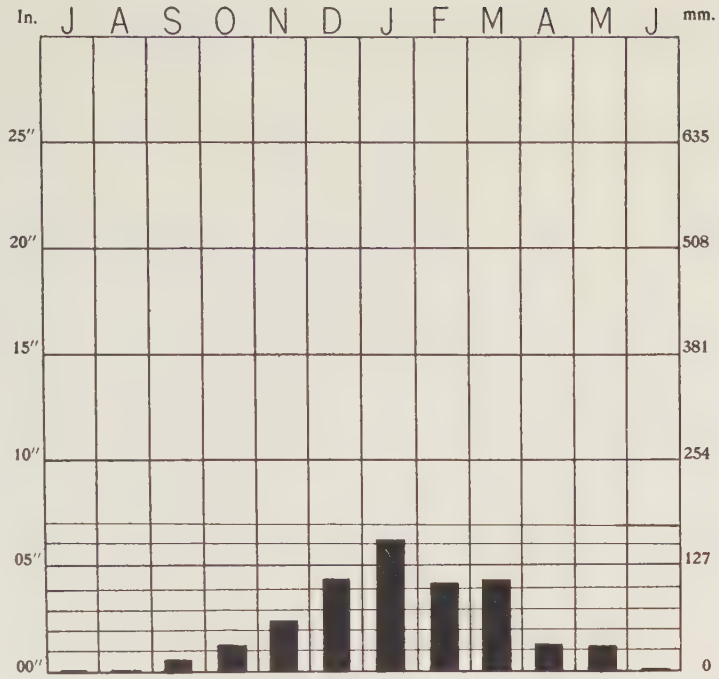
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Fig. 1

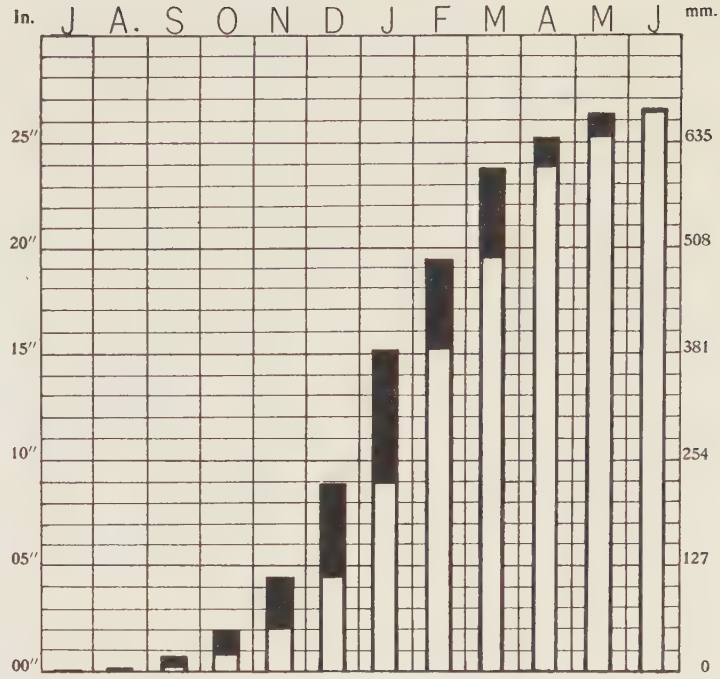
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Fig. 2

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THE MORPHOLOGY OF LANDSCAPE

BY
CARL O. SAUER

INTRODUCTION

Diverse opinions regarding the nature of geography are still common. The label, geography, as is the case with history, is no trustworthy indication as to the matter contained. As long as geographers disagree as to their subject it will be necessary, through repeated definition, to seek common ground upon which a general position may be established. In this country a fairly coherent series of viewpoints has been advanced, especially through presidential addresses before the Association of American Geographers, which may be accepted as mirror and mould of geographic opinion in America. They are sufficiently clear and well known that they need not be restated.[1] In European geography a somewhat different orientation appears to be developing. In various quarters significant activity is being displayed, probably in some measure influenced by anti-intellectualist currents. At any rate a shaking up of some vigor is under way. It may therefore be appropriate to reëxamine the field of geography, keeping current views abroad especially in mind, in order to attempt a working hypothesis that may serve to illuminate in some degree both the nature of the objective and the problem of systematic method.

[1] In particular the following addresses are notable expressions of leading opinion: Davis, W.M., An Inductive Study of the Content of Geography, Bull. Am. Geog. Soc., vol. 38, pp. 67–84 (1906); Fenneman, N. M., The Circumference of Geography, Ann. Assoc. Am. Geog., vol 9, pp. 3–12 (1919); Barrows, H.H., Geography as Human Ecology, *ibid.*, vol. 13, pp. 1–14 (1923).

THE FIELD OF GEOGRAPHY

The phenomenologic view of science.—All science may be regarded as phenomenology,[2] the term science being used in the sense of organized process of acquiring knowledge, rather than in the common restricted meaning of a unified body of physical law. Every field of knowledge is characterized by its declared preoccupation with a certain group of phenomena, which it undertakes to identify and order according to their relations. These facts are assembled with increasing knowledge of their connection; the attention to their connection denotes scientific approach. "A fact is first determined when it is recognized as to limits and qualities, and it is understood when it is viewed in its relations. Out of this follows the necessity of predetermined modes of inquiry and of the creation of a system that makes clear the relation of the phenomena. . . . Every individual science is naïve as a special discipline, in so far as it accepts the section of reality which is its field *tel quel* and does not question its position in the general scene of nature; within these limits, however, it proceeds critically, since it undertakes to determine the connection of the phenomena and their order."[3] According to such definition of the grounds of knowledge, the first concern is with the phenomena that constitute the "section of reality" which is occupied by geography, the next with the method of determining their connection.

Geography as a 'naïvely given section of reality.'—Disagreement as to the content of geography is so great that three distinct fields of inquiry are usually designated as geography: (1) The study of the earth as the medium of physical processes, or the geophysical part of cosmologic science; (2) the study of life-forms as subject to their physical environment, or a part of biophysics, dealing with tropisms; and (3) the study of the areal or habitat differentiation of the earth, or chorology. In these three fields there is partial accordance of phenomena, but little of relation. One may choose between the three; they may hardly be consolidated into one discipline.

The great fields of knowledge exist because they are universally recognized as being concerned with a great category of phenomena. The experience of mankind, not the inquiry of the specialist, has made

[2] v. Keyserling, H., Prolegomena zur Naturphilosophie, p. 11 (1910).

[3] *Ibid.*, pp. 8 and 11.

the primary subdivisions of knowledge. Botany is the study of plants, and geology that of rocks, because these categories of fact are evident to all intelligence that has concerned itself with the observation of nature. In the same sense, area or landscape is the field of geography, because it is a naïvely given, important section of reality, not a sophisticated thesis. Geography assumes the responsibility for the study of areas because there exists a common curiosity about that subject. The fact that every school child knows that geography provides information about different countries is enough to establish the validity of such a definition.

No other subject has preëmpted the study of area. Others, such as historians and geologists, may concern themselves with areal phenomena, but in that case they are avowedly using geographic facts for their own ends. If one were to establish a different discipline under the name of geography, the interest in the study of areas would not be destroyed thereby. The subject existed long before the name was coined. The literature of geography in the sense of chorology begins with parts of the earliest sagas and myths, vivid as they are with the sense of place and of man's contest with nature. The most precise expression of geographic knowledge is found in the map, an immemorial symbol. The Greeks wrote geographic accounts under such designations as periplus, periodos, and periegesis long before the name geography was used. Yet even the present name is more than two thousand years old. Geographic treatises appear in number among the earliest printed books. Explorations have been the dramatic reconnaissances of geography. The great geographic societies, justly have accorded a place of honor to explorers. "Hic et ubique" is the device under which geography has stood always. The universality and persistence of the chorologic interest and the priority of claim which geography has to this field are the evidences on which the case for the popular definition may rest.

We may therefore be content with the simple connotation of the Greek word which the subject uses as its name, and which means most properly areal knowledge. The Germans have translated it as *Landschaftskunde* or *Länderkunde,* the knowledge of landscape or of lands. The other term, *Erdkunde,* the science of the earth in general, is falling rapidly into disuse.

The thought of a general earth science is impossible of realization; geography can be an independent science only as chorology, that is as knowledge of the varying expression of the different parts of the earth's surface. It is, in the first

place, the study of lands; general geography is not general earth science, rather it presupposes the general properties and processes of the earth, or accepts them from other sciences; for its own part it is oriented about their varying areal expression.[4]

With this preference of synthetic areal knowledge to general earth science the entire tradition of geography is in agreement.

The interdependence of areal phenomena.—Probably not even the adherents of other, recent schools of geography would deny place for such a view of the subject, but they deem this naïvely given body of facts inadequate to establish a science, or at the most would consider it an auxiliary discipline which compiles fragmentary evidence, to find its place ultimately in a general geophysical or biophysical system. The argument then is shifted from the phenomenal content to the nature of the connection of the phenomena. We assert the place for a science that finds its entire field in the landscape on the basis of the significant reality of chorologic relation. The phenomena that make up an area are not simply assorted but are associated, or interdependent. To discover this areal "connection of the phenomena and their order" is a scientific task, according to our position the only one to which geography should devote its energies. The position falls only if the non-reality of area be shown. The competence to arrive at orderly conclusions is not affected in this case by the question of coherence or incoherence of the data, for their characteristic association, as we find them in the area, is an expression of coherence. The element of time is admittedly present in the association of geographic facts, which are thereby in large part non-recurrent. This, however, places them beyond the reach of scientific inquiry only in a very narrow sense, for time as a factor has a well-recognized place in many scientific fields, where time is not simply a term for some identifiable causal relation.

Historical development of chorologic relation into scientific system.—The older geography was troubled but little by critique. It was casually, even trivially, descriptive rather than critical. Yet though it is idle to seek in most of this literature a "system which makes clear the relation of the phenomena," we cannot dispose of all of it as accidental or haphazard in content. In some measure the notion of areal interdependence of phenomena as giving rise to areal reality

[4] Hettner, A., Methodische Zeit und Streitfragen, Geog. Ztschr., vol. 29, p. 37 (1923). Hettner is cited here in the latest statement of the position he has defended ably for many years. To American geographers Fenneman's address of 1919, cited above, is ever memorable for its spirited declaration of the same thesis.

was present, as any reader of Herodotus or Polybius knows. The *historia* of the Greeks, with its blurred feeling for time relations, had a somewhat superior appreciation of areal relations and represented a far from contemptible start in geography.[5] However much it may have been embroidered by geophysical, geodetic, and geologic notes, classical geography in general, not cosmology subsequently interpreted by some as geography, gave primary emphasis to areal description, with frequent observations on the interrelation of areal facts. The culminating school, of which Strabo was chief, was by no means entirely naïve, and rejected vigorously other definition of geography than as chorology, with express exclusion of cosmologic philosophy.

During the period of great discoveries a bona fide but uncritical geography attained its greatest development in the numerous travel relations and especially in the cosmographies of that time. An ever increasing body of facts about countries was at that time being brought before the Western World, which took keen interest in the rapidly widening horizon. With such a deluge of newly acquired facts about parts of the world, attempts at systematic ordering were numerous, but often grotesque rather than successful. It is not surprising that dynamic systems of geography should have emerged only as the furore of exploration became spent. Yet it is perhaps even more difficult for us to judge the thought of this period than that of classical antiquity. Yule has helped us to better appreciation of the geographic acumen of some of the men of this period. Of the cosmographers, at least Varenius has been accorded a higher rank than that of a compiler. One very great step in synthesis certainly took place at this time, that of the development of cartography into a real chorologic discipline. Only through a large amount of classification and generalization of geographic data was it possible to consolidate the scattered and voluminous data of exploration into the geographically adequate maps that characterize the latter part of the period. To this day many of the maps of the seventeenth and eighteenth centuries are in some respects monumental. However much may have been added since in precision of measurement, in many ways we have retained the chorologic content as formulated in the maps of this period beginning the 'Age of Surveys.'[6] "Every map which reproduces

[5] v. Humboldt, A., Kosmos (1845), vol. 1, pp. 64, 65: "In classical antiquity the earliest historians made little attempt to separate the description of lands from the narration of events the scene of which was in the areas described. For a long time physical geography and history appear attractively intermingled."

[6] Peschel's *Zeitalter der Messungen.*

the form of the earth's surface is a kind of morphologic representation.''[7] Not only for physical morphology, but for the cultural expression of landscape, these maps represented a highly successful series of solutions that are still used. Without such a preliminary synthesis of the facts of geography the work of the next period would have been impossible.

In the nineteenth century the contest between the cosmologic and the chorologic views became acute and the situation of geography was much in doubt. Rationalism and positivism dominated the work of geographers. The milieu became a leading doctrine and thus continued through the century. Divine law was transposed into natural law, and for geography Montesquieu and Buckle were prophets of major importance. Since natural law was omnipotent the slow marshaling of the phenomena of area become too tedious a task for eager adherents of the faith of causation. The areal complex was simplified by selecting certain qualities, such as climate, relief, or drainage, and examining them as cause or effect. Viewed as end products, each of these classes of facts could be referred back fairly well to the laws of physics. Viewed as agents, the physical properties of the earth, such as climate in particular with Montesquieu, became adequate principles for explaining nature and distribution of organic life. The complex reality of areal association was sacrificed in either case to a rigorous dogma of materialistic cosmology, most notably in American physiography and anthropogeography. About twenty years ago the most distinguished American geographer took the position ''that neither the inorganic nor the organic elements which enter into geographical relations are by themselves of a completely geographic quality; they gain that quality only when two or more of them are coupled in a relation of cause and effect, at least one element in the chain of causation being organic and one inorganic . . . . Any statement is of geographical quality if it contains a reasonable relation between some inorganic element of the earth, acting as a control, and some element of organic existence . . . . serving as a response.'' Indeed in this causal relation was, he said, ''the most definite, if not the only unifying principle that I can find in geography.'' Cause was a confident and alluring word and causal geography had its day. The *Zeitgeist* was distinctly unfavorable to those geographers who thought that the subject was in no wise committed to a rigidly deterministic formula.

[7] Penck, A., Morphologie der Erdoberfläche (1894), vol. 1, p. 2.

Latterly, Vidal de la Blache, in France, Hettner, Passarge, and Krebs, in Germany, and others have been reasserting more and more the classical tradition of geography as chorologic relation. It may be said that, after a period in which special, essentially physical disciplines were most in vogue, we are in process of returning to our permanent task and that this readjustment is responsible for the current activity of inquiry as to content of our field.

Summary of the objective of geography.—The task of geography is conceived as the establishment of a critical system which embraces the phenomenology of landscape, in order to grasp in all of its meaning and color the varied terrestrial scene. Indirectly Vidal de la Blache has stated this position by cautioning against considering "the earth as 'the scene on which the activity of man unfolds itself,' without reflecting that this scene is itself living."[8] It includes the works of man as an integral expression of the scene. This position is derived from Herodotus rather than from Thales. Modern geography is the modern expression of the most ancient geography.

The objects which exist together in the landscape exist in interrelation. We assert that they constitute a reality as a whole which is not expressed by a consideration of the constituent parts separately, that area has form, structure, and function, and hence position in a system, and that it is subject to development, change, and completion. Without this view of areal reality and relation, there exist only special disciplines, not geography as generally understood. The situation is analogous to history, which may be divided among economics, government, sociology, and so on; but when this is done the result is not history.

THE CONTENT OF LANDSCAPE

Definition of landscape.—The term 'landscape' is proposed to denote the unit concept of geography, to characterize the peculiarly geographic association of facts. Equivalent terms in a sense are 'area' and 'region.' Area is of course a general term, not distinctively geographic. Region has come to imply, to some geographers at least, an order of magnitude. Landscape is the English equivalent of the term German geographers are using largely and strictly has the same meaning, a land shape, in which the process of shaping is by no means thought of as simply physical. It may be defined, therefore,

[8] Principes de géographie humaine, p. 6 (1922).

as an area made up of a distinct association of forms, both physical and cultural.[9]

The facts of geography are place facts; their association gives rise to the concept of landscape. Similarly, the facts of history are time facts; their association gives rise to the concept of period. By definition the landscape has identity that is based on recognizable constitution, limits, and generic relation to other landscapes, which constitute a general system. Its structure and function are determined by integrant, dependent forms. The landscape is considered, therefore, in a sense as having an organic quality. We may follow Bluntschli in saying that one has not fully understood the nature of an area until one "has learned to see it as an organic unit, to comprehend land and life in terms of each other."[10] It has seemed desirable to introduce this point prior to its elaboration because it is very different from the unit concept of physical process of the physiographer or of environmental influence of the anthropogeographer of the school of Ratzel. The mechanics of glacial erosion, the climatic correlation of energy, and the form content of an areal habitat are three different things.

Landscape has generic meaning.—In the sense here used, landscape is not simply an actual scene viewed by an observer. The geographic landscape is a generalization derived from the observation of individual scenes. Croce's remark that "the geographer who is describing a landscape has the same task as a landscape painter"[11] has therefore only limited validity. The geographer may describe the individual landscape as a type or possibly as a variant from type, but always he has in mind the generic, and proceeds by comparison.

An ordered presentation of the landscapes of the earth is a formidable undertaking. Beginning with infinite diversity, salient and related features are selected in order to establish the character of the landscape and to place it in a system. Yet generic quality is nonexistent in the sense of the biologic world. Every landscape has individuality as well as relation to other landscapes, and the same is true of the forms that make it up. No valley is quite like any other valley; no city the exact replica of some other city. In so far as these qualities remain completely unrelated they are beyond the reach of

[9] Sölch, J., Auffassung der natürlichen Grenzen (1924), has proposed the term 'Chore' to designate the same idea.

[10] "Die Amazonasniederung als harmonischer Organismus," Geog. Ztschr., vol. 27, p. 49 (1921).

[11] Quoted by Barth, P., Philosophie der Geschichte (ed. 2), p. 10.

systematic treatment, beyond that organized knowledge that we call science. "No science can rest at the level of mere perception..... The so-called descriptive natural sciences, zoology and botany, do not remain content to regard the singular, they raise themselves to concepts of species, genus, family, order, class, type."[12] "There is no idiographic science, that is, one that describes the individual merely as such. Geography formerly was idiographic; long since it has attempted to become nomothetic, and no geographer would hold it at its previous level."[13] Whatever opinion one may hold about natural law, or nomothetic, genetic, or causal relation, a definition of landscape as singular, unorganized, or unrelated has no scientific value.

Element of personal judgment in the selection of content.—It is true that in the selection of the generic characteristics of landscape the geographer is guided only by his own judgment that they are characteristic, that is, repeating; that they are arranged into a pattern, or have structural quality, and that the landscape accurately belongs to a specific group in the general series of landscapes. Croce objects to a science of history on the ground that history is without logical criteria: "The criterion is the choice itself, conditioned, like every economic art, by knowledge of the actual situation. This selection is certainly conducted with intelligence, but not with the application of a philosophic criterion, and is justified only in and by itself. For this reason we speak of the fine tact, or scent, or instinct of the learned man."[14] A similar objection is sometimes urged against the scientific competence of geography, because it is unable to establish complete, rigid logical control and perforce relies upon the option of the student. The geographer is in fact continually exercising freedom of choice as to the materials which he includes in his observations, but he is also continually drawing inferences as to their relation. His method, imperfect as it may be, is based on induction; he deals with sequences, though he may not regard these as a simple causal relation.

If we consider a given type of landscape, for example a North European heath, we may put down notes such as the following:

The sky is dull, ordinarily partly overcast, the horizon is indistinct and rarely more than a half-dozen miles distant, though seen from a height. The upland is gently and irregularly rolling and descends to broad, flat basins. There are no

[12] Barth, *op. cit.*, p. 11.

[13] *Ibid.*, p. 39.

[14] On History, pp. 109, 110. The statement applies to the history that has the goal simply of "making the past live again." There is, however, also a phenomenologic history, which may discover related forms and their expression.

long slopes and no symmetrical patterns of surface form. Watercourses are short, with clear brownish water, and perennial. The brooks end in irregular swamps, with indistinct borders. Coarse grasses and rushes form marginal strips along the water bodies. The upland is covered with heather, furze, and bracken. Clumps of juniper abound, especially on the steeper, drier slopes. Cart traces lie along the longer ridges, exposing loose sand in the wheel tracks, and here and there a rusty, cemented base shows beneath the sand. Small flocks of sheep are scattered widely over the land. The almost complete absence of the works of man is notable. There are no fields or other enclosed tracts. The only buildings are sheep sheds, situated usually at a distance of several miles from one another, at convenient intersections of cart traces.

The account is not that of an individual scene, but a summation of general characteristics. References to other types of landscape are introduced by implication. Relations of form elements within the landscape are also noted. The items selected are based upon "knowledge of the actual situation" and there is an attempt at a synthesis of the form elements. Their significance is a matter of personal judgment. Objective standards may be substituted for them only in part, as by quantitative representation in the form of a map. Even thus the personal element is brought only under limited control, since it still operates in choosing the qualities to be represented. All that can be expected is the reduction of the personal element by agreeing on a "predetermined mode of inquiry," which shall be logical.

Extensiveness of areal features.—The content of landscape is something less than the whole of its visible constituents. The identity of the landscape is determined first of all by conspicuousness of form, as implied in the following statement: "A correct representation of the surface form, of soil, and of surficially conspicuous masses of rock, of plant cover and water bodies, of the coasts and the sea, of areally conspicuous animal life and of the expression of human culture is the goal of geographic inquiry."[15] The items specified are chosen because the experience of the author has shown their significance as to mass and relation. The chorologic position necessarily recognizes the importance of areal extensiveness of phenomena, this quality being inherent in the position. Herein lies an important contrast between geography and physiography. The character of the heath landscape described above is determined primarily by the dominance of sand, swamp, and heather. The most important geographic fact about Norway, aside from its location, probably is that four-fifths of its surface is barren highland, supporting neither forests nor flocks, a condition significant directly because of its extensiveness.

[15] Passarge, Grundlagen der Landschaftskunde, vol. 1, p. 1 (1920).

Habitat value as a basis for the determination of content.—Personal judgment of the content of landscape is determined further by interest. Geography is distinctly anthropocentric, in the sense of value or use of the earth to man. We are interested in that part of the areal scene which concerns us as human beings because we are part of it, live with it, are limited by it, and modify it. Thus we select those qualities of landscape in particular that are or may be of use to us. We relinquish those features of area that may be significant to the geologist in earth history but are of no concern in the relation of man to his area. The physical qualities of landscape then are those that have habitat value, present or potential.

The natural and the cultural landscape.—"Human geography does not oppose itself to a geography from which the human element is excluded; such a one has not existed except in the minds of a few exclusive specialists."[16] It is a forcible abstraction, by every good geographic tradition a *tour de force,* to consider a landscape as though it were devoid of life. Because we are interested primarily in "cultures which grow with original vigor out of the lap of a maternal natural landscape, to which each is bound in the whole course of its existence,"[17] geography is based on the reality of the union of physical and cultural elements of the landscape. The content of landscape is found therefore in the physical qualities of area that are significant to man and in the forms of his use of the area, in facts of physical background and facts of human culture. A valuable discussion of this principle is given by Krebs under the title "Natur- und Kulturlandschaft."[18]

For the first half of the content of landscape we may use the designation 'site,' which has become well established in plant ecology. A forest site is not simply the place where a forest stands; in its full connotation, the name is a qualitative expression of place in terms of forest growth, usually for the particular forest association that is in occupation of the site. In this sense the physical area is the sum of all natural resources that man has at his disposal in that area. It

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16 Vidal de la Blache, P., *op. cit.,* p. 3.

17 Spengler, O., Untergang des Abendlandes, vol. 1, p. 28 (1922–23): "Kulturen die mit urweltlicher Kraft aus dem Schoose einer mütterlichen Landschaft, an die jede von ihnen im ganzen Verlauf ihres Daseins streng gebunden ist, erblühen."

18 Ztschr. Gesell. f. Erdkunde, Berlin (1923), p. 83. He states the content of geography as being "in the area (Raum) itself with its surfaces, lines, and points, its form, circumference, and content. The relations to geometry, the pure areal science, become even more intimate, when not only the area as such, but its position with reference to other areas is considered."

is beyond his power to add to them; he may 'develop' them, ignore them in part, or subtract from them by exploitation.

The second half of landscape viewed as a bilateral unit is its cultural expression. There is a strictly geographic way of thinking of culture; namely, as the impress of the works of man upon the area. We may think of people as associated within and with an area, as we may think of them as groups associated in descent or tradition. In the first case we are thinking of culture as a geographic expression, composed of forms which are part of geographic phenomenology. In this view there is no place for a dualism of landscape.

The Application of the Morphologic Method

Form of induction.—The systematic organization of the content of landscape proceeds with the repression of a priori theories concerning it. The massing and ordering of phenomena as forms that are integrated into structures and the comparative study of the data as thus organized constitute the morphologic method of synthesis, a special empirical method. Morphology rests upon the following postulates: (1) that there is a unit of organic or quasi-organic quality, that is, a structure to which certain components are necessary, these component elements being called 'forms' in this paper; (2) that similarity of form in different structures is recognized because of functional equivalence, the forms then being 'homologous'; and (3) that the structural units may be placed in series, especially into developmental sequence, ranging from incipient to final or completed stage. Morphologic study does not necessarily affirm an organism in the biologic sense, as, for example, in the sociology of Herbert Spencer, but only organized unit concepts that are related. Without being committed in any sense to a general biogenetic law, the organic analogy has proved most useful throughout the fields of social inquiry. It is a working device, the truth of which may perhaps be subject to question, but which leads nevertheless to increasingly valid conclusions.[19]

The term 'morphology' originated with Goethe and expresses his contribution to modern science. It may be well to recall that he turned to biologic and geologic studies because he was interested in the nature and limits of cognition. Believing that there were things "accessible and inaccessible" to human knowledge, he concluded:

[19] The assumption 'as if,' advanced by Vaihinger as "Philosophie des Als Ob."

"One need not seek for something beyond the phenomena; they themselves are the lore (Lehre)." Thus originated his form studies, and especially those of homology of form. His method of scientific inquiry rested on a definite philosophic position.

If therefore the morphologic method appears unpretentious to the student who is eager to come to large conclusions, it may be pointed out that it rests upon a deliberate restraint in the affirmation of knowledge. It is a purely evidential system, without prepossession regarding the meaning of its evidence, and presupposes a minimum of assumption; namely, only the reality of structural organization. Being objective and value-free, or nearly so, it is competent to arrive at increasingly significant results.

Application to social studies.—Morphologic method is not only the introduction to the biologic sciences but it is steadily growing in importance in the social fields. In biology it is the study of organic forms and their structure, or the architecture of organisms. In the social field the continued synthesis of phenomena by morphologic method has been employed with greatest success perhaps in anthropology. This science can claim an honor roll of workers who have had the patience and skill to approach the study of social institutions phenomenologically, by the classification of forms, ranging from the concrete materials of clothing, housing, and tools to the language and customs of a group, thereby identifying step by step the complex structure of cultures. Spengler's recent brilliant and highly controversial thesis of history is far and away the most pretentious application of the method to the human field. Disregarding its elements of intuitionalism, it is in effect comparative morphology as applied to history, the second volume bearing that title. He characterizes the forms that, to his mind, compose the great historic structures, subjects them to comparison for different periods as homologies, and traces developmental stages. By however much the author may have exceeded his and our knowledge in his daring synthesis, he has shown the possibilities of a morphology of history, or of the study of history on a scientific basis other than the causal formula of historical rationalism.[20]

[20] Untergang des Abendlandes. The mathematico-philosophical thesis of the cultural cycle, the complete antithesis of Buckle, in particular is of such importance that it should be known to every geographer, whatever his position may be with reference to Spengler's mysticism. There are at least three other similar views of the structure of history, apparently independently discovered; Frobenius' Paideuma (1921), Henry Adams' "Rule of Phase in History" (*in* The Degradation of the Democratic Dogma, 1919), and Flinders Petrie's Revolutions of Civilization (1911).

The introduction of morphology into geography and the results.— Method and term were first formally introduced into geography by Karl Ritter, whose restoration of geography succeeded finally, not in the idealistic cosmology he had espoused, but because after all he laid the foundations for comparative regional study. Thereafter, perhaps because there was so much to do, the morphologic studies were rapidly narrowed so as to regard only the surficial form of the land. Griesebach's classic definition that "the morphologic system illuminates, by regarding the relationship of forms, the obscurity of their descent"[21] was applied with fateful results to the field of geography. The restriction of forms to relief, and interest in the origin of these forms, shortly established, under the leadership of Peschel, v. Richthofen, and de la Noë, the genetic inquiry that was called geomorphology.[22] At first relying on the naïve descriptive classification of surface forms, as for example in Penck's Morphologie der Erdoberfläche, which is chorologic morphology, increasingly the trend was to classify on the basis of process, and to trace these forms back to more and more remote forms. The genetic historians of land form undertook increasingly the invasion of the field of geology. The final step was that some of these specialists lost sight almost completely of actual land forms and devoted themselves to the construction of theoretical forms deduced from individual physical processes. The defeat of geographic ends was therefore almost complete and such geomorphology became a separate branch of general earth science.

This autonomous genetic morphology inevitably led to an adverse reaction among the chorologically minded geographers, not because the work was not carefully done, nor because it failed to develop a valuable field of knowledge, but because it became unrecognizable as geography.[23] Unfortunately a very general name was applied to a very specialized discipline. Under a misapprehension of the term there has been a tendency to disregard in consequence the possibilities of the morphologic method. Vidal de la Blache perhaps earlier than any one else realized the situation and reëstablished morphology in its rightful position. The regional monographs that proceeded from his school expressed far more adequately than had been done before the full form content and structural relation of the landscape, finding in the cultural landscape the culminating expression of the organic area.

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[21] Vegetation der Erde, vol. 1, p. 10 (1884).

[22] Penck, *op. cit.*, vol. 1, pp. 5, 6.

[23] Hettner, *op. cit.*, pp. 41–46.

In these studies, for example, the position of man and his works explicitly is that of the last and most important factor and forms in the landscape.

The perversion of geographic ends in the definition of morphology as the causal study of relief forms appears from the following considerations: (1) Relief is only one category of the physical landscape and ordinarily not the most important one; it almost never supplies the complete basis of a cultural form. (2) There is no necessary relation between the mode of origin of a relief form and its functional significance, the matter with which geography is most directly concerned. (3) An inevitable difficulty with a purely genetic morphology of relief forms is that most of the actual relief features of the earth are of very mixed origin. Behind the present forms lie processal associations, previous or ancestral forms, and almost inscrutable expressions of time. For the present at least, therefore, genetic morphology isolates those form elements that yield to causal analysis. In the selection of those relief facts that are legible as to genesis, it neglects some, even many, of the features of relief and abandons therefore the structural synthesis of even this segment of the landscape in so far as chorology is concerned.

In the late enthusiasm for studies of relief forms the climatologists were crowded into a relatively obscure position. Yet they, most largely, escaped the geographically sterile pursuit of the pure genetic method. Climatology has been phenomenologic rather than genetic. In spite of very scant knowledge of the origin of climatic conditions, the facts of climate have been summarized in terms of their geographic significance most admirably. In particular Köppen's series of trials at climatic synthesis, carefully developed as to biotically critical values, admirably restrained as to genetic explanation, are among the most important if not the most important contribution in this generation to a general geographic morphology. Yet such is the force of associations that few doubtless would name such climatic synthesis as a fundamental part of geographic morphology. It is more than a matter of mere nomenclature to object to the misapplication of the term morphology; it is a rut into which we have slipped and which has limited our range. Perhaps some of the cross-purposes in present-day geography may be traced to the failure to recognize that all the facts of the subject are to be organized by a general system, through which alone their relation may be determined.

Preparatory Systematic Description

The first step in morphologic study.—Historically "geography commenced by describing and registering, that is as a systematic study. It proceeded thereupon to . . . . genetic relation, morphology."[24] The geographic study is still thus begun. The description of observed facts is by some predetermined order that represents a preliminary grouping of the material. Such systematic description is for the purpose of morphologic relation and is really the beginning of morphologic synthesis. It is therefore distinguishable from morphology not at all in principle but in that it lies at a lower critical level. The relation is not dissimilar to that between taxonomy and biologic morphology.

Descriptive terminology.—The problem of geographic description differs from that of taxonomy principally in the availability of terms. The facts of area have been under popular observation to such an extent that a new terminology is for the most part not necessary. Salisbury held that the forms of landscape had generally received serviceable popular names and that codification might proceed from popular parlance without the coining of new terms. Proceeding largely in this manner, we are building up a list of form terms, that are being enriched from many areas and many languages. Very many more are still awaiting introduction into geographic literature. These terms apply as largely to soil, drainage, and climatic forms as they do to land surface. Also popular usage has named many vegetational associations and has prepared for us a still largely unprospected wealth of cultural form terms. Popular terminology is a fairly reliable warrant of the significance of the form, as implied in its adoption. Such names may apply to single form constituents, as glade, tarn, loess. Or they may be form associations of varying magnitude, as heath, steppe, piedmont. Or they may be proper names to designate unit landscapes, as, for example, the regional names that are in use for most parts of France. Such popular nomenclature is rich in genetic meaning, but with sure chorologic judgment it proceeds not from cause but from a generic summation; namely, from form similarities and contrasts.

If systematic description is a desideratum for geography, we are still in great need of enlarging our descriptive vocabulary. The meagerness of our descriptive terms is surprising by comparison with

[24] Krebs, *op. cit.*, p. 81.

other sciences. Contributing causes may be the idiographic tradition of unrelated description, and the past predilection for process studies which minimized the real multiplicity of forms.

The predetermined descriptive system.—The reduction of description to a system has been largely opposed by geographers and not entirely without cause. Once this happens the geographer is responsible within those limits for any areal study he undertakes; otherwise he is free to roam, to choose, and to leave. We are not concerned here with geography as an art. As a science it must accept all feasible means for the regimentation of its data. However excellent the individualistic, impressionistic selection of phenomena may be, it is an artistic, not a scientific desideratum. The studies in geomorphology, in particular those of the school of Davis, represent perhaps the most determined attempt to oppose uncontrolled freedom of choice in observation by a strict limitation of observations and of method. Different observations may be compared as to their findings only if there is a reasonable agreement as to the classes of facts with which they deal. The attempt at a broad synthesis of regional studies by employing our existing literature immediately runs into difficulties, because the materials do not fit together. Findings on the most important theme of human destructiveness of natural landscape are very difficult to make because there are no adequate points of reference. Some observers note soil erosion systematically, others casually, and still others may pay no attention to it. If geography is to be systematic and not idiosyncratic, there must be increasing agreement as to items of observation. In particular this should mean a general descriptive scheme to be followed in the collection of field notes.[25].

A general descriptive scheme, intended to catalogue areal facts broadly, without proceeding at this stage from hypothetical origins and connections, has been recently proposed by Passarge under the name "*Beschreibende Landschaftskunde.*"[26] It is the first comprehensive treatment of this subject since v. Richthofen's Führer für Forschungsreisende, written just prior to the most flourishing period of geomorphology (1886). The work of Passarge is somewhat rough hewn and it is perhaps excessively schematic, yet it is the most adequate consideration by far that the whole matter of geographic description has had. Its express purpose is "first of all to determine the facts and to attempt a correct presentation of the significant,

[25] Sauer, C. O., The Survey Method in Geography, Ann. Assoc. Am. Geog., vol. 14, pp. 19 ff. (1924).

[26] Grundlagen der Landschaftskunde, vol. 1.

visible facts of area without any attempt at explanation and speculation."[27] The plan provides

"for the systematic observation of the phenomena that compose the landscape. The method resembles most closely the chrie, a device for the collection of material in theme writing. It helps to see as much as possible and to miss as little as possible and has the further advantage that all observations are ordered. If earlier geographers had been familiar with a method of systematic observation of landscape, it would have been impossible for the characteristic red color of tropical residual soils to have escaped attention until v. Richthofen discovered that fact."[28]

Passarge proceeds with an elaborate schedule of notes covering all form categories of the landscape, beginning with atmospheric effects and ending with forms of habitation. From these he proceeds to a descriptive classification of form associations into larger areal terms. For the further elaboration of the plan the reader is referred to the volume in question, as worthy of careful consideration.

The author has applied his system elsewhere to the 'pure' as against the 'explanatory' description of areas, as for example in his characterization of the Valley of the Okavango, in the northern salt steppe of the Kalahari.[29] That he succeeds in giving to the reader an adequate picture of the composition of area will probably be admitted.

One may note that Passarge's supposedly purely descriptive procedure is actually based on large experience in areal studies, through which a judgment as to the significant constituents of landscape has been formed. These are really determined through morphologic knowledge, though the classification is not genetic, but properly based on the naïvely generic forms. The capacious dragnet which Passarge has fashioned, though disclaiming all attempt at explanation, is in reality a device fashioned by experienced hands for catching all that may be wanted in an areal morphology and for deferring explanation until the whole material is sorted.

Forms of Landscape and Their Structure

The division between natural and cultural landscapes.—We cannot form an idea of landscape except in terms of its time relations as well as of its space relations. It is in continuous process of development or of dissolution and replacement. It is in this sense a true appreciation of historical values that has caused the geomorphologists to tie the present physical landscape back into its geologic origins, and to derive it therefrom step by step. In the chorologic sense,

[27] *Ibid.*, p. vi. [28] *Ibid.*, p. 5. [29] Hamburg Mitt. Geog. Gesell., 1919, No. 1.

however, the modification of the area by man and its appropriation to his uses are of dominant importance. The area prior to the introduction of man's activity is represented by one body of morphologic facts. The forms that man has introduced are another set. We may call the former, with reference to man, the original, natural landscape. In its entirety it no longer exists in many parts of the world, but its reconstruction and understanding are the first part of formal morphology. Is it perhaps too broad a generalization to say that geography dissociates itself from geology at the point of the introduction of man into the areal scene? Under this view the prior events belong strictly in the field of geology and their historical treatment in geography is only a descriptive device employed where necessary to make clear the relationship of physical forms that are significant in the habitat.

The works of man express themselves in the cultural landscape. There may be a succession of these landscapes with a succession of cultures. They are derived in each case from the natural landscape, man expressing his place in nature as a distinct agent of modification. Of especial significance is that climax of culture which we call civilization. The cultural landscape then is subject to change either by the development of a culture or by a replacement of cultures. The datum line from which change is measured is the natural condition of the landscape. The division of forms into natural and cultural is the necessary basis for determining the areal importance and character of man's activity. In the universal, but not necessarily cosmologic sense, geography then becomes that part of the latest or human chapter in earth history which is concerned with the differentiation of the areal scene by man.

The natural landscape: geognostic basis.—In the subsequent sections on the natural landscape a distinction is implied between the historical inquiry into origin of features and their strictly morphologic organization into a group of forms, fundamental to the cultural expression of the area. We are concerned alone with the latter in principle, with the former only as descriptive convenience.

The forms of the natural landscape involve first of all the materials of the earth's crust which have in some important measure determined the surface forms. The geographer borrows from the geologist knowledge of the substantial differences of the outer lithosphere as to composition, structure, and mass. Geology, being the study of the history of these materials, has devised its classification on the basis of succession of formations, grouped as to period. In formations per

se the geographer has no interest. He is concerned, however, with that more primitive phase of geology, called geognosy, which regards kind and position of material but not historical succession. The name of a geologic formation may be meaningless geographically, if it lumps lithologic differences, structural differences, and differences in mass under one term. Geognostic condition provides a basis of conversion of geologic data into geographic values. The geographer is interested in knowing whether the base of a landscape is limestone or sandstone, whether the rocks are massive or intercalated, whether they are broken by joints or are affected by other structural conditions expressed in the surface. These matters may be significant to the understanding of topography, soil, drainage, and mineral distribution.

The application of geognostic data in geographic studies is usual in a sense, areal studies being hardly feasible without some regard for the underlying materials. Yet to find the most adequate analysis of the expression of the underlying materials in the surface, it is probably necessary to go back to the work of the older American and British geologists, such as Powell, Dutton, Gilbert, Shaler, and Archibald Geikie. In the aggregate, of course, the geologic literature that touches upon such matters is enormous, but it is made up of rather incidental and informal items, because landscape is not in the central field of interest of the geologist. The formal analysis of critical geognostic qualities and their synthesis into areal generalizations has not had a great deal of attention. Adequately comparable data are still insufficient from the viewpoint of geography. In briefest form Sapper has lately attempted a general consideration of the relation of geologic forms to the landscapes of varying climates, to the illumination of the entire subject of regional geography.[30]

Rigorous methodologist that he is, Passarge has not failed to scrutinize the geographic bearing of rock character and condition, and has applied in intensive areal study the following observations (somewhat adapted):[31]

Physical resistance
- Soft, easily eroded formations
- Rocks of intermediate resistance
  - much broken (*zerklüftet*)
  - moderately broken
  - little broken
- Rocks of high resistance
  - as above

[30] Sapper, K., Geologischer Bau und Landschaftsbild (1917).

[31] Physiologische Morphologie, Hamburg Mitt. Geog. Gesell., vol. 26, pp. 133 ff. (1912).

Chemical resistance and solubility
Easily soluble
highly permeable
moderately permeable
relatively impermeable
Moderately subject to solution and chemical alteration
as above
Resistant

In a later study he added provision for rocks notably subject to creep (*fluktionsfähig*).[32] An interpretation of geologic conditions in terms of equivalence of resistance has never been undertaken for this country. It is probably possible only within the limits of a generally similar climatic condition. We have numerous classifications of so-called physiographic regions, poorly defined as to their criteria, but no truly geognostic classification of area, which, together with relief representation, and climatic areas, alone is competent to provide the base map of all geographic morphology.

The natural landscape: climatic basis.—The second and greater link that connects the forms of the natural landscape into a system is climate. We may say confidently that the resemblance or contrast between natural landscapes in the large is primarily a matter of climate. We may go farther and assert that under a given climate a distinctive landscape will develop in time, the climate ultimately cancelling the geognostic factor in many cases.

Physiography, especially in texts, has, largely, either ignored this fact or has subordinated it to such an extent that it is to be read only between the lines. The failure to regard the climatic sum of physiographic processes as differing greatly from region to region may be due to insufficient experience in different climatic areas and to a predilection for deductive approach. Most physiographic studies have been made in intermediate latitudes of abundant precipitation, and there has been a tendency to think of the agencies in terms of a standardized climatic milieu. The appreciation even of one set of phenomena, as for example drainage forms, is likely to be too much conventionalized by applying the schematism of standardized physiographic process and its results to New England and the Gulf states, to the Atlantic and the Pacific coasts, not to mention the deserts, the tropics, and the polar margins.

But, if we start from the areal diversity of climates, we consider at once differences in penetration of heat and cold diurnally and seasonally, the varying areal expression of precipitation as to amount, form, intensity, and seasonal distribution, the wind as a factor vary-

[32] Morphologie des Messtischblattes Stadtremda, *ibid.*, vol. 28, pp. 1 ff. (1914).

ing with area, and above all the numerous possibilities of combination of temperature, precipitation, dry weather, and wind. In short, we place major emphasis on the totality of weather conditions in the moulding of soil, drainage, and surface features. It is geographically much more important to establish the synthesis of natural landscape forms in terms of the individual climatic area than to follow through the mechanics of a single process, rarely expressing itself individually in a land form of any great extent.

The harmony of climate and landscape, insufficiently developed by the schools of physiography, has become the keystone of geographic morphology in the physical sense. In this country the emergence of this concept is to be sought largely in the studies in the arid and semi-arid West, though they did not result at once in the realization of the implied existence of a distinct set of land forms for every climate. In the morphologic form category of soils, the climatic factor was fully discovered first at the hand of Russian students, and was used by them as the primary basis of soil classification [33] in a more thoroughgoing manner than that which had been applied to topographic forms.[34] Under the direction of Marbut the climatic system has become basal to the work of the U. S. Bureau of Soils. Thus the ground was prepared for the general synthesis of physical landscape in terms of climatic regions.[35] Most recently, Passarge, using Köppen's climatic classification, has undertaken a comprehensive methodology on this basis.[36]

The relation of climate to landscape is expressed in part through vegetation, which arrests or transforms the climatic forces. We, therefore, need to recognize not only the presence or absence of a cover of vegetation, but the type of cover that is interposed between the exogenous forces of climate and the materials of the earth and that acts on the materials beneath.

Diagrammatic representation of the morphology of the natural landscape.—We may now attempt a diagram of the nature of physical morphology to express the relation of landscape, constituent forms, time, and connecting causal factors:

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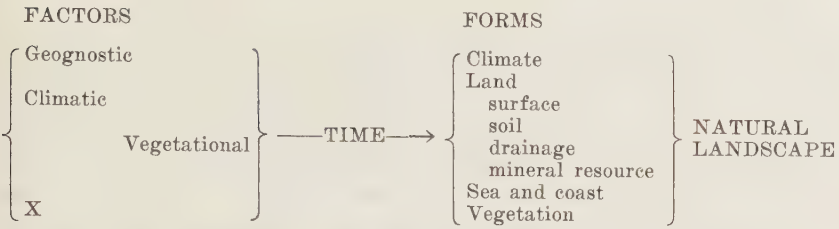
[33] Glinka, K., Typen der Bodenbildung (1914); revised and extended by Ramann, E., Bodenbildung und Bodeneinteilung (1918).

[34] For desert forms there was in existence the synthesis of Johannes Walther, Das Gesetz der Wüstenbildung, first published in 1900.

[35] Excellently done by Sapper, cited above, but also strongly emphasized by Davis, W. M., and Braun, G.; Physiogeographie (ed. 2, 1916), vol. 2, especially in the final chapters.

[36] Grundlagen der Landschaftskunde, vols. 2 and 3.



The thing to be known is the natural landscape. It becomes known through the totality of its forms. These forms are thought of not for and by themselves, as a soil specialist would regard soils, for example, but in their relation to one another and in their place in the landscape, each landscape being a definite combination of form values. Behind the forms lie time and cause. The primary genetic bonds are climatic and geognostic, the former being in general dominant and operating directly as well as through vegetation. The 'X' factor is the pragmatic 'and,' the always unequated remnant. These factors are justified as a device for the connection of the forms, not as the end of inquiry. They lead toward the concept of the natural landscape which in turn leads to the cultural landscape. The character of the landscape is determined also by its position on the time line. Whether this line is of determinate or infinite length does not concern us as geographers. In some measure, certainly, the idea of a climax landscape is useful, a landscape that, given a constancy of impinging factors, has exhausted the possibilities of autogenous development. Through the medium of time the application of factor to form as cause and effect relation is limited; time itself is a great factor. We are interested in function, not in a determination of cosmic unity. For all chorologic purposes the emphasis of the diagram lies at its right hand; time and factor have only an explanatory descriptive rôle.

This position with reference to the natural landscape involves a reaffirmation of the place of physical geography, certainly not as physiography nor geomorphology as ordinarily defined, but as physical morphology which draws freely from geology and physiography certain results to be built into a view of physical landscape as a habitat complex. This physical geography is the proper introduction to the full chorologic inquiry which is our goal.

Forms of the natural landscape: climate.—In the physical structure of landscape, climate is first in importance. In the diagram it appears at the head of the list of forms and also as the major factor behind the whole category of forms. As a form, climate is an areal

expression, the sum of the atmospheric features of the area. This is the sense in which it is treated in climatology. In American literature climates were first introduced prominently as areal forms, fundamental to geography in general, through Tower's chapters on climate in Salisbury, Barrows, and Tower's Elements of Geography. The value of this view has been demonstrated by the steadily increasing rôle which climatology has played in the fundamental courses of instruction. In no respect are we as near to general agreement as in this.

Climatology is areal reality; meteorology is general process. The contrast is that between physical geography and physiography.

Land forms in the natural landscape.—The land includes four edaphic elements or properties analogous to the climatic elements; namely, surface or land form in the narrow sense, soil, drainage, and mineral forms. In the case of surface forms we are dealing with a body of fact that is of interest to geomorphology, to physiography, and to geographic morphology. The first is concerned with history, the second with process, the third with description and relation to other forms. For our purposes surface forms are to be regarded as climates are in climatology. Strictly we are concerned with the character of relief only, that is, with expressions of slope and exposure in relation to the other constituent forms of the landscape. The topographic map, interpreted in terms of use significance of different slopes, is in principle the complete chorologic representation of surface form. The relation of surface form to climate is so close that the grouping of surfaces by climates is warranted generally. Geognostic relation of surface also lends itself well to the areal grouping of land forms. The further penetration into genesis of forms leads increasingly away from geographic ends. Restraint in this respect is necessary and is attained through a proper realization of the goal of areal reality.

The areal differentiation of soils fundamentally is based on differences of productivity, or their habitat significance. Soils as areal form constituents are primarily grouped by climates; the secondary classification is geognostic and therefore also chorologically satisfactory. The placing of soils into the structure of landscape therefore presents little difficulty, the soil survey being in fact a highly specialized form of physical geography. Unlike some physiographers and geomorphologists, the field student of soils is not pursuing a non-geographic end, but is limiting himself to a small part of the geographic field.

Drainage forms are of course direct expressions of climate, and the most feasible classification of streams, swamps, and bodies of standing water is in climatic terms. For instance, moors are a type of high latitude swamp, permanent features under conditions of low evaporation. Their growth is especially favored by the presence of certain plants, such as sphagnum moss. Their position is not restricted to lowlands, but they extend over fairly irregular surfaces by the expansion of a marginal zone of spongy vegetation. These swamps illustrate the interrelation of physical areal forms. Under them a distinctive soil is developed and even the subsoil is altered. This swampy covering also protects the land surface it has occupied from the attacks of running water and wind and moulds it into broadly rounded forms. Where climate conditions are not favorable to the development of such swamps, both in still higher and in lower latitudes, the forms of drainage, soil, and surface change markedly.

Mineral resources belong among the physical forms under the view of the physical landscape as a human habitat. Here the geognostic factor dominates genetically. The diagrammatic relation still holds in a measure, because of the concentration of minerals due to underground waters both at and beneath the surface. It would be pedantic to urge this point strongly, nor are we desirous to urge genetic relation as a necessary principle.

Forms of the sea in the natural landscape.—The relation of sea to land is organizable on the same basis of climate and geognosy. The seacoasts are in the main an expression of tectonic history and of climatic setting. Areally, climates afford the broader basis of classification, because elevation and subsidence of coasts have varied and are changing, as to direction and amount, so greatly, over short distances, as to make a tectonic classification of seashores chorologically unsatisfactory. The seas themselves are obviously as intimately related to climate as is the land. Their currents, surface conditions, density, and temperatures are as certainly to be classified in climatic terms as land forms.

Vegetation forms in the natural landscape.—A. v. Humboldt was first to recognize through systematic observations, the importance of vegetation in the character of the landscape. "However much the character of the different parts of the world depends on the totality of external appearances; though outline of mountains, physiognomy of plants and animals, cloud forms and transparency of the atmosphere compose the general impression: yet it is not to be denied that the

most important element in this impression is the cover of vegetation.''[37] The bonds between climate and vegetation are so direct and strong that a large measure of climatic grouping of vegetation forms is possible. Some plant geographers have found the classification of vegetational associations most desirable in terms of thermal or moisture belts.[38]

Summary of the form relations in the natural landscape.—The large emphasis on climate in the previous statements does not mean that geography is to be transformed into climatology. The physical area is fundamental to any geographic study because it furnishes the materials out of which man builds his culture. The identity of the physical area rests fundamentally on a distinctive association of physical forms. In the physical world, generic character of area and its genesis are coupled so closely that the one becomes an aid to the recognition of the other. In particular, climate, itself an areal form, largely obscure as to origin, so largely controls the expression of the other physical forms that in many areas it may be considered the determinant of form association. An express disclaimer may be entered, however, against the notion of the necessity of a genetic bond in order to organize the phenomenology of the natural landscape. The existence of such bonds has been determined empirically. By regarding the relationship of forms we have discovered an important light on ''the obscurity of their descent,'' but as geographers we are not enjoined to trace out the nature of this descent. This remains the problem of geomorphology, which indeed now appears more complicated than ever, the validity of climatic control and of great secular changes of climate being accepted.

Thus far the way is pretty well marked. We know the 'inorganic' composition of landscape fairly well, and, except for a somewhat excessive aloofness existing between plant and general geography, the place of vegetation in the landscape is properly cared for.[39]

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[37] Ansichten der Natur, vol. 2, p. 20 (1849).

[38] The content of the preceding pages, dealing with the morphologic structure of physical area, is adapted from Sauer and Leighly, Syllabus for an Introduction to Geography (1924).

[39] Hettner, *op. cit.*, p. 39, comments as follows on biogeography: ''The great majority of studies in plant and animal geography have been made by botanists and zoologists, even though these works do not always completely satisfy our geographic needs. The botanist and zoologist are concerned with plants and animals, we with lands . . . . When they carry on plant and animal geography in this narrower sense, as for example, Griesebach, in his brilliant volume on the vegetation of the earth, they are doing geographic work, in the same manner as meteorologists who concern themselves with climatology; for the purpose is geographic, the results fit more closely into the structure of geographic instruction than into that of botany or zoology, and the whole process of thought and inquiry, oriented as it is about climate and soil, is geographic. We geographers are

The extension of morphology to the cultural landscape.—The natural landscape is being subjected to transformation at the hands of man, the last and for us the most important morphologic factor. By his cultures he makes use of the natural forms, in many cases alters them, in some destroys them.

The study of the cultural landscape is, as yet, largely an untilled field. Recent results in the field of plant ecology will probably supply many useful leads for the human geographer, for cultural morphology might be called human ecology. In contrast to the position of Barrows in this matter, the present thesis would eliminate physiologic ecology or autecology and seek for parallels in synecology. It is better not to force into geography too much biological nomenclature. The name ecology is not needed: it is both morphology and physiology of the biotic association. Since we waive the claim for the measurement of environmental influences, we may use, in preference to ecology, the term morphology to apply to cultural study, since it describes perfectly the method that is involved.

Among geographers in America who have concerned themselves with systematic inquiry into cultural forms, Mark Jefferson, O. E. Baker, and M. Aurousseau have done outstanding pioneering. Brunhes' "essential facts of geography" represent perhaps the most widely appreciated classification of cultural forms.[40] Sten DeGeer's population atlas of Sweden[41] was the first major contribution of a student who has concentrated his attention strictly on cultural morphology. Vaughan Cornish introduced the concepts of 'march,' 'storehouse,' and 'crossroads' in a most valuable contribution to urban

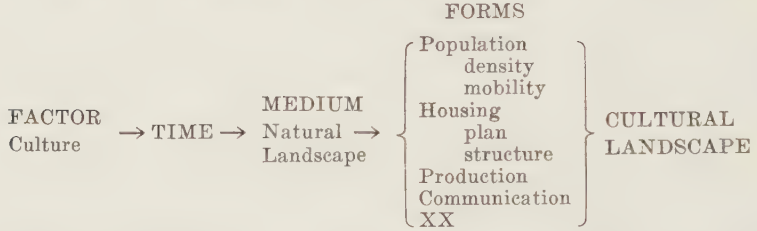
far from being jealous on that account; on the contrary, we acknowledge such aid gratefully; but rightly we have commenced also to do plant and animal geography, because certain problems concern us more than they do those who are not geographers and because we possess certain valuable preparations for such studies." The work of plant and animal geographers illustrates the partial artificiality of academic compartments. They require so specialized a training that ordinarily they are professionally classed as botanists and zoologists. Their method, however, is geographic to such an extent and their findings are so significant to geography that their work is more appreciated and perhaps even better evaluated by geographers than by biologists generally. Occasional field biologists, such as Bates, Hudson, and Beebe, have done work which encompasses so large a part of the landscape that they are really geographers of the highest accomplishment. It is, however, true that vegetation or fauna may be regarded somewhat differently as a part of the human habitat (economic plant and animal geography?) than as a part of botany or zoology. In this lies the justification of Hettner's recommendation for participation by the geographer in plant and animal studies. Now and then a geographer, as for instance Gradmann and Waibel, has mastered the field of biogeography to the enrichment of his whole position.

[40] Brunhes, J., Human Geography (1910, Am. ed., 1920).

[41] Befolkningens Fördeliing i Sverige (Stockholm, 1917).

problems.[42] Most recently, Geisler has undertaken a synthesis of the urban forms of Germany, with the deserved subtitle: "A contribution to the morphology of the cultural landscape."[43] These pioneers have found productive ground; our periodical literature suggests that a rush of homesteaders may soon be under way.

Diagrammatic representation of the morphology of the cultural landscape.—The cultural landscape is the geographic area in the final meaning (*Chore*). Its forms are all the works of man that characterize the landscape. Under this definition we are not concerned in geography with the energy, customs, or beliefs of man but with man's record upon the landscape. Forms of population are the phenomena



of mass or density in general and of recurrent displacement, as seasonal migration. Housing includes the types of structures man builds and their grouping, either dispersed as in many rural districts, or agglomerated into villages or cities in varying plans (*Städtebild*). Forms of production are the types of land utilization for primary products, farms, forests, mines, and those negative areas which he has ignored.

The cultural landscape is fashioned out of a natural landscape by a culture group. Culture is the agent, the natural area is the medium, the cultural landscape the result. Under the influence of a given culture, itself changing through time, the landscape undergoes development, passing through phases, and probably reaching ultimately the end of its cycle of development. With the introduction of a different, that is, alien culture, a rejuvenation of the cultural landscape sets in, or a new landscape is superimposed on remnants of an older one. The natural landscape is of course of fundamental importance, for it supplies the materials out of which the cultural landscape is formed. The shaping force, however, lies in the culture itself. Within the wide limits of the physical equipment of area lie many possible choices for man, as Vidal never grew weary of pointing out.

[42] The Great Capitals (London, 1923).

[43] Die deutsche Stadt (Stuttgart, 1924).

This is the meaning of adaptation, through which, aided by those suggestions which man has derived from nature, perhaps by an imitative process, largely subconscious, we get the feeling of harmony between the human habitation and the landscape into which it so fittingly blends. But these, too, are derived from the mind of man, not imposed by nature, and hence are cultural expressions.

Morphology as Applied to the Branches of Geography

The consolidation of the two diagrams gives an approximation of the total scientific content of geography on the phenomenologic basis by which we have proceeded.[44] They may readily be expressed so as to define the branches of geography. (1) The study of the form categories per se in their general relation, the system of the forms of landscape, is morphology in the purely methodologic sense and is the equivalent of what is called, especially in France and Germany, general geography, the propaedeutic through which the student learns to work with his materials. (2) Regional geography is comparative morphology, the process of placing individual landscapes into relation to other landscapes. In the full chorologic sense, this is the ordering of cultural, not of natural, landscapes. Such a critical synthesis of regions for the entire world is the latest contribution of Passarge, who has thereby nearly rounded out a critique of the entire field of geography.[45] (3) Historical geography may be considered as the series of changes which the cultural landscapes have undergone and therefore involves the reconstruction of past cultural landscapes. Of special concern is the catalytic relation of civilized man to area and the effects of the replacement of cultures. From this difficult and little touched field alone may be gained a full realization of the development of the present cultural landscape out of earlier cultures and the natural landscape. (4) Commercial geography deals with the forms of production and the facilities for distribution of the products of areas.

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[44] The conclusions presented in this paper are substantially in agreement with Sten DeGeer's article On the Definition, Method, and Classification of Geography, Geog. Annaler, 1923, pp. 1–37, with the contrast that a 'concrete' *landscape* takes the place of DeGeer's 'abstract' *areal relation.*

[45] Vergleichende Landschaftskunde (Berlin, 1923); Landschaftsgürtel der Erde (Breslau, 1923).

Beyond Science

The morphologic discipline enables the organization of the fields of geography as positive science. A good deal of the meaning of area lies beyond scientific regimentation. The best geography has never disregarded the aesthetic qualities of landscape, to which we know no approach other than the subjective. Humboldt's 'physiognomy,' Banse's 'soul,' Volz's 'rhythm,' Gradmann's 'harmony' of landscape, all lie beyond science. They seem to have discovered a symphonic quality in the contemplation of the areal scene, proceeding from a full novitiate in scientific studies and yet apart therefrom. To some, whatever is mystical is an abomination. Yet it is significant that there are others, and among them some of the best, who believe, that having observed widely and charted diligently, there yet remains a quality of understanding at a higher plane which may not be reduced to formal process.[46]

DIVERGENT VIEWS OF GEOGRAPHY

The geographic thesis of this article is so largely at variance with certain other views of the subject that it may be desirable to set forth in summary form what has been expressed and implied as to contrast in the several positions.

Geomorphology as a branch of geography.—German geographers in particular tend to regard geomorphology as an essential division of geography, and use largely the term '*Oberflächengestaltung*,' or the record of development of surficial form. The forms considered are ordinarily topographic only. The content of geomorphology has been most broadly defined by Penck,[47] who included the following forms: plains, hill surfaces, valleys, basins, mountains, cavernous forms, seacoasts, seafloors, islands. These descriptive topographic terms are studied by geomorphology as to their derivation, not as to use significance.

Geomorphology being the history of topography, it derives present surfaces from previous forms and records the processes involved. A

[46] A good statement of current searchings in this field is by Gradmann, R., Das harmonische Landschaftsbild, Ztschr. Gesell. Erdk., Berlin, 1924, pp. 129–147. Banse has been publishing since 1922 a non- or antiscientific journal, Die Neue Geographie, in which numerous good items are enclosed in a repellently polemic shell.

[47] Morphologie der Erdoberfläche (1894), vol. 2.

study of the geomorphology of the Sierra Nevada is a history of the sculpturing of the mountain massif, concerned with the uplift of the earth block, and the stages of modification in which erosional processes, secondary deformations, and structural conditions are in complex relations. Relief features in this sense are the result of the opposition of orogenic and degradational processes through geologic periods of time. Certain features, such as peneplains and terrace remnants, thus have high diagnostic value in reading the record of modification of surface. These elements of the landscape, however, may be of little or no significance in the chorologic sense. To geomorphology the peneplain has been extremely important; the trend of geography has not been notably affected by its discovery. Out of the topographic complex the geomorphologist may select one body of facts illustrative of earth history, the geographer will use a largely different set of facts which have habitat significance.

The geomorphologist, therefore, is likely to be a specialized historical geologist, working on certain, usually late, chapters of earth history. Conventional historical geology is mostly concerned with the making of rock formations. The geomorphologist directs attention to erosional and deformational surfaces in the record of the rocks. To such an extent has this been the American orientation that we have in our country little geomorphologic work of recent date that is consciously geographic in purpose, that is, descriptive of actual land surfaces.

The geomorphologist can and does establish a connection between the fields of geography and geology and his labors further our own work. He advances our studies of landscape materially where he has preceded the geographer, and we properly regard him potentially as much a collaborator in geography as in geology. One of the present needs in American geography is a greater familiarity with and application of geomorphologic studies.

Physiography and physical geography.—When Huxley reapplied the term physiography he disclaimed expressly the desire to reform physical geography. He was not lecturing, he said, "on any particular branch of natural knowledge, but on natural phenomena in general."[48] The subtitle of his treatise read: "An Introduction to the Study of Nature." He chose the Basin of the Thames as the area for his demonstration, not through chorologic interest, but in

[48] Physiography (1877), p. vi.

order to show that any area contained abundant material for the demonstration of the general laws of physical science. Huxley said:

> I endeavored to show that the application of the plainest and simplest processes of reasoning to any of these phenomena, suffices to show, lying behind it, a cause, which will again suggest another; until, step by step, the conviction dawns upon the learner that, to attain to even an elementary conception of what goes on in his parish he must know something about the universe; that the pebble he kicks aside, would not be what it is and where it is, unless a particular chapter of the earth's history, finished untold ages ago, had been exactly what it was.[49]

The two central ideas in his mind were the unity of physical law as shown by the features of the earth and the evolutionary march of the geologic record. It was the bright hour of dawn in scientific monism, with Huxley officiating at the observation of the lands. Physiography served in such a canonical rôle in elementary scientific education until a later age of machinery sent it into the discard in favor of 'general science.'

Physiography is still the general science of the earth, and concerns itself with the physical processes that operate at the surface of the earth and in the earth's crust. We still find the captions that Huxley introduced into his text: the work of rain and rivers, ice and its work, the sea and its work, earthquakes and volcanoes. These things have chorologic expression but they are studied as general processes. As an investigator the physiographer must be above all things a physicist, and increasing demands are made on his physical and mathematical knowledge. The way of the development of physiography as research is through geophysical institutes. Academically it fits in best as a part of dynamic geology. The geographer probably needs to know little more of it than he should know of historical geology.

One may question, therefore, the propriety of such terms as regional physiography and physiographic regions. They contradict the essential meaning of the subject and ordinarily mean rather a loose form of geomorphology, which of necessity has areal expression. Physiography was conceived as a purely dynamic relation and is categorically incapable of consistent areal expression unless it becomes also a name applied to physical geography or to geomorphology.

Geographic morphology vs. 'geographic influences.'—The study of the physical environment as an active agency has recently been subjected to trenchant criticism by L. Febvre, with an equally incisive

[49] *Ibid.*, pp. vii, viii.

foreword by Henri Berr.[50] Both thoroughly relish the chance to riddle this geographic ambition. Geography as they see it is "to give an example of the true task of synthesis. . . . The effort of synthesis is a directed activity; it is not a premature realization."[51] Questions of environment "may have for the geographer their interest; but they are not his end. He must guard well against acclaiming as 'scientific' verities theories of adaptation 'simpliste' in character which more competent people are in process of completing or correcting."[52] "What is, then, the commendable attitude in human geography? It can consist only in searching for the relations which exist between earth and life, the rapport which exists between the external milieu and the activity of the occupants."[53] Vidal de la Blache's thesis that in the relation of man to the earth there exists less of necessary adaptation than of 'possibilisme' is worked out with skill and conviction. Excepting for their spirited devotion to the master of French geography, the authors are not really familiar with geographic thought. They do not fairly represent the tenets of geography because they know chiefly the publicists of environmentalism, against whom they consider Vidal as the outstanding bulwark. Vidal will have an honored place in the history of geography, but we are no longer much impressed by his concern to establish decently good relations with rationalistic thought. Rationalism has seen better days than these; we no longer need to come to terms with it by diplomatic compromise. In spite of the deficient orientation in geographic thought, the volume directs a quality of dialectic at one geographic school which entitles it to high rank in geographic criticism.

In this country the theme that geography is the study of natural environment has been dominant in the present generation. It has come to be advertised abroad that such is the American definition of geography.[54]. The earliest term was 'environmental control.' This was succeeded by 'response,' 'influence,' 'adjustment,' or some other word that does not change the meaning, but substitutes a more cautious term for the ringing declaration of control. All these positions are mechanistic. In some way they hope to measure the force that physical environment exerts over man. The landscape as such has no

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50 La terre et l'évolution humaine (Paris, 1922).

51 *Ibid.*, p. ix.

52 *Ibid.*, p. 11.

53 *Ibid.*, p. 12.

54 Van Valkenburg, Amsterdam Tijdschr., K. Ned. Aardr. Gesell., vol. 41, pp. 138, 139 (1924).

interest for them, but only those cultural features for which a causal connection with the physical environment can be established. The aim, therefore, is to make of geography a part of biophysics, concerned with human tropisms.

Geographic morphology does not deny determinism, nor does it require adhesion to that particular faith in order to qualify in the profession. Geography under the banner of environmentalism represents a dogma, the assertion of a faith that brings rest to a spirit vexed by the riddle of the universe. It was a new evangel for the age of reason, that set up its particular form of adequate order and even of ultimate purpose. The exposition of the faith could proceed only by finding testimonials to its efficacy. To the true believer there were visible evidences of the existence of what he thought should be, which were not to be seen by those who were weak in the faith. Unless one has the proper temperament, the continued elaboration of this single thesis with the weak instruments at his hand becomes dreadfully monotonous. In such a study one knows beforehand that one will encounter only variants of the one theme of 'influence.'

The narrowly rationalistic thesis conceives of environment as process and of some of the qualities and activities of man as products. The agency is physical nature; man responds or adapts himself. Simple as the thesis sounds, it incurs continually grave difficulties in the matching of specific response to specific stimulus or inhibition. The direct influence of environmental stimuli is purely somatic. What happens to man through the influence of his physical surroundings is beyond the competence of the geographer; at most he may keep informed as to physiologic research in that field. What man does in an area because of tabu or totemism or because of his own will involves use of environment rather than the active agency of the environment. It would, therefore, appear that environmentalism has been shooting neither at cause nor at effect, but rather that it is bagging its own decoys.[55]

[55] Kroeber, A. L., Anthropology (1923), pp. 180–193, 502–503, scrutinizes the ex parte nature of environmentalist tenets in their relation to culture.

Conclusion

In the colorful reality of life there is a continuous resistance of fact to confinement within any 'simpliste' theory. We are concerned with "directed activity, not premature realization" and this is the morphologic approach. Our naïvely selected section of reality, the landscape, is undergoing manifold change. This contact of man with his changeful home, as expressed through the cultural landscape, is our field of work. We are concerned with the importance of the site to man, and also with his transformation of the site. Altogether we deal with the interrelation of group, or cultures, and site, as expressed in the various landscapes of the world. Here are an inexhaustible body of fact and a variety of relation which provide a course of inquiry that does not need to restrict itself to the straits of rationalism.[56]

[56] Wissler, Clark, Ecology, vol. 5, p. 311 (1924): "While the early history of the concept is probably lost to us forever, there are not wanting indications that the ecological idea was conceived in the same atmosphere as the theory of design, or of purposeful adaptation. However that may be, the effort on the part of later professors of ecology has been to eschew all such philosophies except the fundamental assumption that plants and the rest of nature are intimately interdependent one upon the other." Thus "the anthropologist is not only trying to show what all the forms and forces of nature have done to man, but even with more emphasis what man has done to nature." (312) This definition of anthropology includes a very large part of the social field, and is also a good definition for geography. At present anthropology is the study of culture per se. If our studies of man and his work have large success in synthesis, a gradual coalescence of social anthropology and of geography may represent the first of a series of fusions into a larger science of man.

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GRAPHIC STUDIES IN CLIMATOLOGY

I. GRAPHIC REPRESENTATION OF A CLASSIFICATION OF CLIMATES

BY
JOHN B. LEIGHLY

I. INTRODUCTION

The primary data of climatic study are quantitative, the results of measurement of climatic elements by means of meteorologic instruments. In the application of such data to the uses of the geographer, however, there is necessary a process of abstraction and generalization, in which the quantitative character is only too frequently lost. This loss would not be a matter of concern were there general agreement among geographers as to the climatic concepts most useful to them, but one frequently encounters either numerical tables poorly assimilated into the text and, in consequence, likely to remain uninterpreted by the reader, or easy generalizations for which a factual basis is not established, or at least not submitted. The problem is to steer a course between the Scylla of unreadable and indeed preliminary tabulations and the Charybdis of concepts controlled by numerical data basic to their demonstration. Generalization and abstraction there must be, and, as well, a fundamental reliance upon numerical data, if geography is to avail itself adequately of essential facts. It is by graphic means alone that primary climatic data may be rendered comprehensible without sacrificing the objective character which is the unique property of quantitative measurements. This fact has long been known to students of climate, and many ingenious and illuminating graphic devices have been produced. There still exist, however, problems in number in the generalization of climatic data for distinctly geographic, as against meteorologic, purposes.

The problem of classification has engaged the attention of many students of climate, and the sum of their efforts at inclusive systems is

a panorama of the entire field of climatic variation. The successive attempts of Wladimir Köppen in this direction[1] have represented high points in synthetic climatology for the past half-century. Especially valuable, from whatever standpoint the subject is approached, is the latest of these, first published in 1918, and reproduced, with minor changes, in Köppen's summary work, *Die Klimate der Erde* (1923). Representing as it does the culmination of a long and active lifetime of study which has embraced practically every branch of climate, it stands unrivaled in the quality of its synthesis.

For the geographer, as opposed to the student of climate *per se*, Köppen's classification is of particular interest. The climatic types erected serve not only as a systematization of climatic data, but may also be considered fundamental groupings of the physical conditions under which the features of the earth's surface are developing and from which these features may have received their most characteristic stamp. It has been made the basis of at least one systematic classification of the features of the earth's surface,[2] and it displays an unusually clear insight into the distribution of primary qualities of landscape. Further study will modify in minor degree the definition of some of the boundary lines between individual climatic types; in the interest of detail, it will be advisable, in intensive study of small areas, to create subdivisions of the types; and such modifications are entirely within Köppen's intention. But certainly there exists no other system of classification yielding equally valid and varied geographic concepts, and it is with the classification of Köppen that the graphic trials here described have been made.

Köppen's system, in spite of its great advantages, has, strangely, not been incorporated into the literature of geography in the United States. Two reviews only,[3] accompanied by an indifferent black-and-white reproduction of the original colored map, have appeared. At least a part of the comparative neglect of so useful a contribution may be attributed to the apparent complexity of the classification, and to the further indubitable fact that the critical values used in the definition of the types are unfamiliar and not readily learned. A recent

[1] "Die Wärmezonen der Erde," Meteor. Ztschr., vol. 1 (1884), pp. 215–226; "Klassifikation der Klimate, vorzugesweise in ihrer Beziehungen zur Pflanzenwelt," Geog. Ztschr., 1900, pp. 593 ff., and 657 ff.; "Klassifikation der Klimate nach Temperatur, Niederschlag und Jahreslauf," Pet. Mitt., vol. 64 (1918), pp. 193–203, 243–248.

[2] Passarge, S., *Grundlagen der Landschaftskunde.* His primary subdivisions of the earth (*"Formengürtel"*) are practically the areas of distribution of Köppen's climates.

[3] Ward, R. Dec., Geog. Rev., Sept., 1919, pp. 188–191, and James, P. E., Monthly Weather Review, Feb., 1922, pp. 69–72.

appraiser of climatologic literature[4] voices the latter objection in these words: "Köppen's system is colorless and dry, because in the designation of individual climatic types it deliberately makes exclusive use of numerical climatic values." Nevertheless, it may well be mentioned, much of the value of the classification lies in just this characteristic! The types recognized are exactly defined. Whoever applies the classification to any part of the earth, will arrive at the same results as another who works with the same observational data. In this quality the classification excels all others in general use in the United States today. Yet, though the divers climates of the earth are thus rigidly defined, the validity of the concepts they represent is established. Furthermore, the use of quantitative definition does not exclude the use, when advisable, of a qualitative characterization of the same climatic groups.

The particular difficulty in the ready apprehension of the Köppen classification lies in the necessity of taking, as climatic values yielding significant boundary lines or zones of climate, unfamiliar numerical expressions. Moreover, in the evaluation of moisture contrasts, there is used a variable relation between rainfall and temperature. The results of exhaustive study as crystallized in the final product are precisely stated; but the difficulty of grasping the classification is increased by the very procedure which makes it so valuable.

It is the aim of this paper to describe certain simple graphic devices in which the essentials of the classification are reduced to a few figures based on rectangular coördinates, and to suggest a means for its application to stations and areas through the medium of graphs. It is believed that these graphs present the system in a form which is more readily grasped than is the original description, and that, at the same time, they make possible the ready climatic classification of any station or area. The figures are based on Köppen's latest statement.[5] In this, a few values are changed slightly from those presented in the 1918 paper. Throughout, the critical values of the original description have been changed to the units of measurement in use in the United States—the Fahrenheit temperature scale and the English system of linear measure. Temperatures are given in their exact Fahrenheit equivalent, and centimeters are expressed in inches according to the approximate relation 5 cm. = 2 in.

[4] Obst, E., "*Die Klimate und ihre geographische Verbreitung,*" *Enzyklopädie der Erdkunde Lufthülle und Klima* (Leipzig und Wien, 1923), p. 163.

[5] Köppen, W., *Die Klimate der Erde* (Berlin, W. de Gruyter Co., 1923). It has not seemed necessary or advisable to review the classification here. For this, the reader is better referred to the original or to the reviews cited above.

II. DESCRIPTION OF THE FIGURES

A. *Temperature—*

The preliminary differentiation of the climates of the earth, in the broadest sense, is according to temperature. The definitive temperature values used in the Köppen classification, both for the major and the minor climatic categories, are represented in figure 1. In the figure the letter symbols used in the designation of the temperature groups are entered in the appropriate parts of the drawing. The figure is an adaptation of one presented in the 1918 paper referred to above.[6] In redrawing the figures as reproduced here, the values have been changed to the Fahrenheit scale, and the order has been reversed on the left-to-right axis. The latter change was made in order to give the temperature groups an order in the figure corresponding to their normal order of discussion. The first large group, the tropical climates, is therefore assigned to the most prominent position in the figure, the upper left. Some of the minor features of the original have been omitted.

In the original paper, this figure was used to indicate the limits within which the temperatures of the entire earth vary. It is here reproduced, in the belief that it illustrates in the best possible manner the temperature classes basic to the system.

In addition to representation of the classification, the figure may be used to good effect in comparing the temperatures of different areas, of whatever magnitude. Without exaggeration, a figure of this sort is a veritable touchstone in the diagnosis of temperature relations.[7] Characteristic, or rather critical temperatures for the two seasons of the year place any station or area in relation to other regional units. In figures 2 to 7 the variation in temperature within each of the continents is illustrated by plotting representative stations in their appropriate positions in the basic diagram, or appropriate parts thereof, and enclosing the area thus arrived at with a dotted line.[8]

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[6] Pl. 11, fig. 3*b*. It is to be regretted that this figure is not reproduced in *Die Klimate der Erde,* in which all the other admirable illustrations of the 1918 paper are incorporated.

[7] The praise of course belongs to Köppen. The writer hopes only, by application, to rescue the figure from the obscurity attendant upon its long neglect by climatologic and geographic literature.

[8] For the names of the stations represented by the letters and the numbers, and their temperatures, see Appendix. Two classes of stations were used: the larger number are well-known places, entered to facilitate mutual comparison; and a few, usually less known, represent extremes. The former are identified

It will be recognized that, from the viewpoint of logic, these figures are the converse of temperature maps. Maps of temperature distribution illustrate the variations of temperature within the frame of the earth's surface or parts thereof; these figures show, as it were, the distribution of points or areas within the frame of possible temperature variation. Obviously, comparison of temperatures takes place within the latter "frame," instead of in the former. Usually, the localization of the thought-processes is subconscious. The figures here reproduced are to be conceived as an effort toward a concrete representation of the actual mental procedure. The range of usefulness, in the application to particular areas, is only suggested by the following demonstrations.

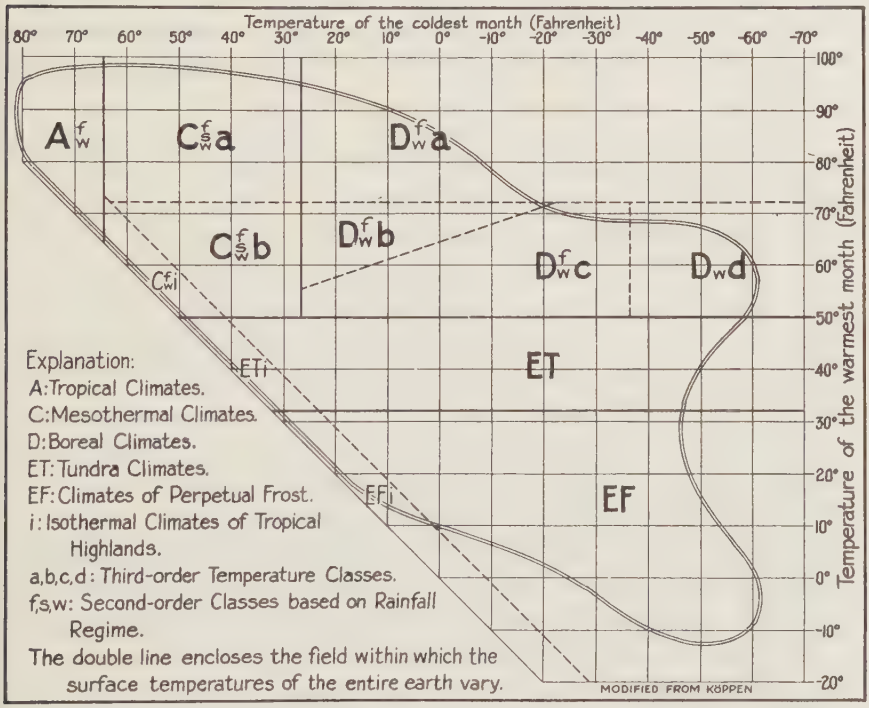

Temperature of the coldest month (Fahrenheit)
80° 70° 60° 50° 40° 30° 20° 10° 0° -10° -20° -30° -40° -50° -60° -70°
100° 90° 80° 70° 60° 50° 40° 30° 20° 10° 0° -10° -20°
Temperature of the warmest month (Fahrenheit)
A_w^f
$C_{sw}^f a$
$D_w^f a$
$C_{sw}^f b$
$D_w^f b$
$D_w^f c$
$D_w d$
C_{wi}^f
ET
EF
Explanation:
A: Tropical Climates.
C: Mesothermal Climates.
D: Boreal Climates.
ET: Tundra Climates.
EF: Climates of Perpetual Frost.
i: Isothermal Climates of Tropical Highlands.
a,b,c,d: Third-order Temperature Classes.
f,s,w: Second-order Classes based on Rainfall Regime.
The double line encloses the field within which the surface temperatures of the entire earth vary.
MODIFIED FROM KÖPPEN

Fig. 1. The primary temperature groups in the climates of the earth.

The continents are arrayed in order of decreasing complexity of thermal structure. Asia (fig. 2), with its great area and range of latitude, stands first. Within this gigantic land mass appears almost the entire range of temperature variation of the earth's surface. Next

by numbers, the latter by small letters. Large dots are used in outlining the area based upon actual observed temperatures, whereas small dots are used for the parts which rest upon computed values. A line left open indicates the lack of data for places (usually mountain peaks), which, if known, would extend the curve in the direction toward which the line is open.

in order is North America (fig. 3), in which the extent of the temperature field is reduced by the elimination of the most extreme continental localities and the highest mountains.

Within the larger field of the North American continent, the distribution of the temperatures of California is of interest. This state contributes two extremes to the continental field: the highest summer temperatures, in the arid lands of the south, and a marine mesothermal climate with a very small annual range. A narrow strip along the coast of the middle part of the state, about Point Reyes, possesses a climatic type not recognized by Köppen.[9] In the literal symbolism of the classification, it would be designated *Csi*. Data for the mountain peaks of the state are not available, hence the curve is not closed. The sharply limited difference between the temperatures of the warmest and the coldest months, which exceeds 20° F. only in the arid sections, is notable.

For conventional reasons Europe is separated from Asia, with which it should logically be combined. The tropical and the more extreme continental localities are not developed in this land mass, and its figure (fig. 4) is therefore conspicuously smaller than the two preceding ones. The slight range of temperature within the tropics, and the narrowing of the continent in higher latitudes, gives to the figure for South America (fig. 5) an extremely attenuated form, parallel to the axis of no annual range. The effect of the absence of stations of even moderately high latitude appears distinctly in the graph outline of Africa (fig. 6). Despite its great area, its field of temperature variation is but little larger than that of California. The greatest monotony of all the continents is displayed by Australia (fig. 7).

In figure 8, the temperatures from a number of oceanic islands, having a great range of latitude, are combined. The very limited range of temperature suggests the possibility of developing a quantitative definition of insular temperatures.

B. *Precipitation*—

The critical moisture relations of the land are those obtaining in the soil. Because of the meagerness of data on this important point, and the difficulty of obtaining them, it is necessary to take, as our nearest measurable approximation of the moisture element, the familiar depth of precipitation. But the moisture relations of climates cannot

[9] "A difference of less than 5° between the means of the coldest and warmest months is not found on the land beyond the tropics."—*Die Klimate der Erde*, p. 123.

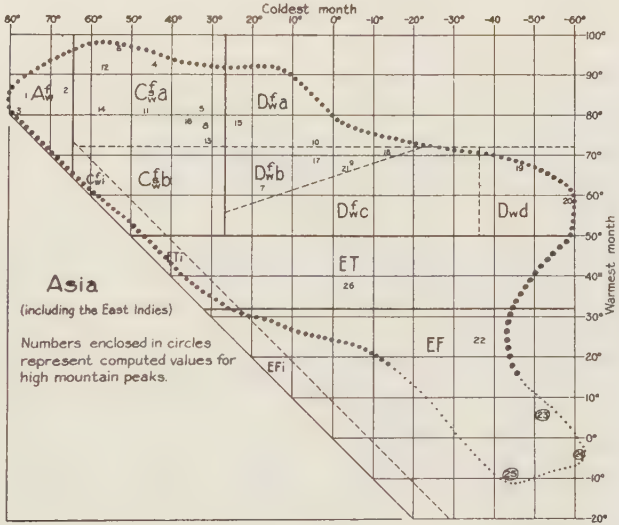


Fig. 2

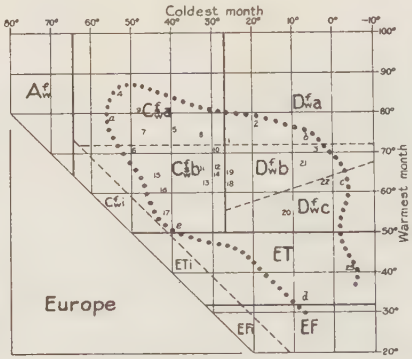


Fig. 4

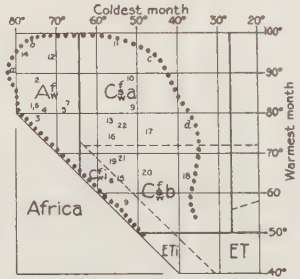


Fig. 6

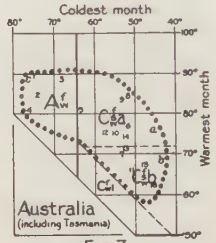


Fig. 7

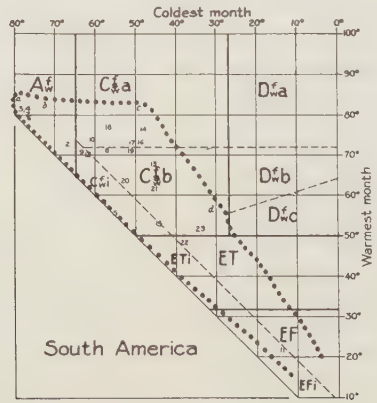
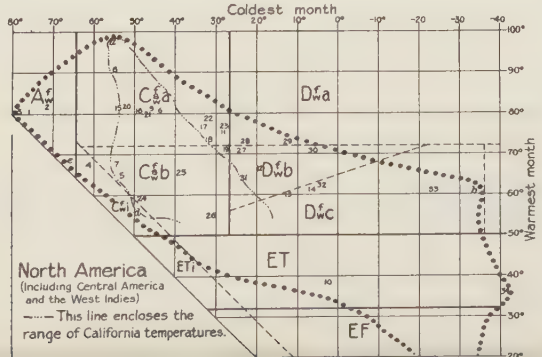
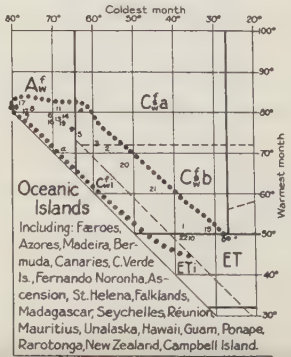


Fig. 5




Coldest month
Warmest month
Oceanic Islands
Including: Færoes, Azores, Madeira, Bermuda, Canaries, C. Verde Is., Fernando Noronha, Ascension, St. Helena, Falklands, Madagascar, Seychelles, Réunion, Mauritius, Unalaska, Hawaii, Guam, Ponape, Rarotonga, New Zealand, Campbell Island.
Af
Cfa
Cfb
ET
ETi

be characterized by a bare statement of this value. The amount of water available for the physical and chemical processes which determine the features of the landscape is concurrently conditioned by evaporation. The quantitative definition of climatic groups on the basis of moisture therefore presents difficulties. In the Köppen classification, the definition of the steppe and the desert climates, together constituting a major group (*B*) coördinate with the largest temperature classes, was arrived at empirically. Since the most important determinant of evaporation is temperature, the final definition of the dry climates and their limitation against the rain or forest climates, were based upon a relation as simple as possible between the annual means of precipitation and temperature. Varying seasonal distribution of the precipitation is of necessity, also regarded.

The following table presents the critical values used in the case of the three main classes of seasonal distribution of rainfall. In the formulae, *Ns* represents the mean annual precipitation in centimeters on the moister limit of the steppe, i.e., the boundary between steppe and forest climates; *Nw* is the mean annual depth of precipitation on the moister limit of the desert, i.e., on the boundary between desert and steppe; *t* the mean annual temperature in degrees Centigrade:

For stations with:

	Ns=	*Nw*=
Uniform distribution of precipitation throughout the year	$t+33$	$t+16\frac{1}{2}$
Summer rain, winter drought	$t+44$	$t+22$
Winter rain, summer drought	$t+22$	$t+11$

When the temperature values are changed to the Fahrenheit temperature scale and the inch scale (5 cm. equaling 2 in.) for depth of precipitation, the relation, of course, is not so simple and the values above become the following, in which tF represents temperature in degrees Fahrenheit, and *Ns* and *Nw* are expressed in inches:

For stations with:

	Ns=	*Nw*=
Uniform distribution of precipitation throughout the year	$tF+27.4$	$tF-2.3$
	$\frac{4.5}{}$	$\frac{4.5}{}$
Summer rain, winter drought	$tF+47.2$	$tF+7.6$
	$\frac{4.5}{}$	$\frac{4.5}{}$
Winter rain, summer drought	$tF+7.6$	$tF-12.2$
	$\frac{4.5}{}$	$\frac{4.5}{}$

In figure 9, these values are presented by plotting the curves of the above equations within the part of the field which corresponds to actuality. The origin of coördinates is taken in the upper left of the figures, for the sake of convenience in arrangement of the types distinguished. The bands at the left of the figure—cross-sections of the ideal 'frame' of variation—give the designations of the types illustrated and of the boundary lines. The distinction between the dry climates with cold winters (k in the literal nomenclature) and the hot (h), dry climates is made by means of a line corresponding to the distinguishing mean annual temperature, 64.4° F. (18° C).[10]

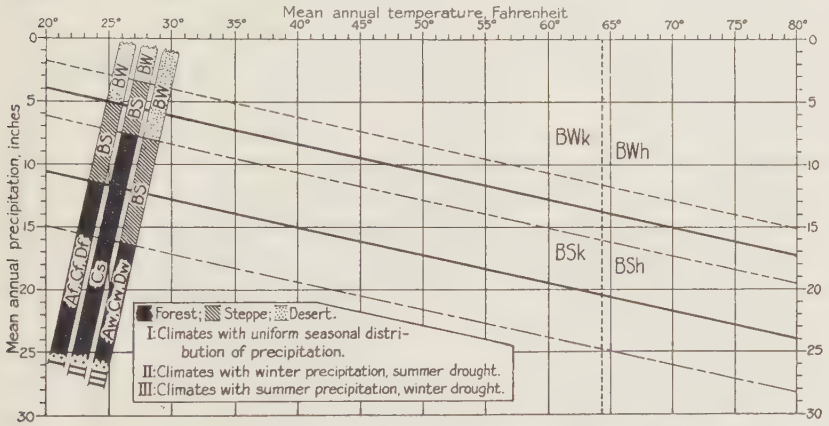
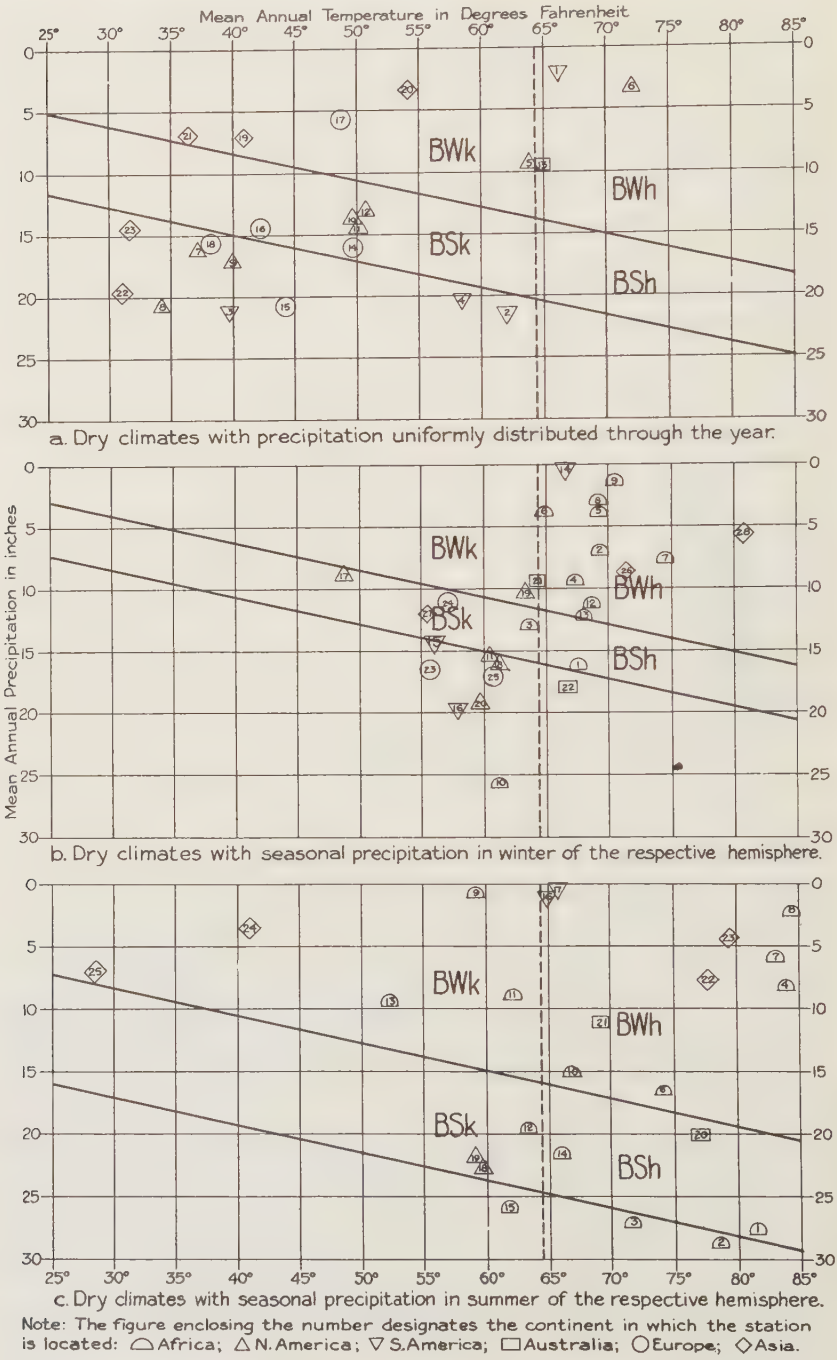


Fig. 9. The critical lines in the definition of the dry climates.

Figure 9 may, in addition to recording graphically the critical values of the classification, illuminate the relation of seasonal distribution to the effectiveness of precipitation. If the uniform distribution of rainfall be taken as the simplest case, and the position of the critical lines for the other two régimes be compared with that of the boundary lines for this distribution, it is seen that conditions of aridity assert themselves with *larger* total rainfall amounts when the precipitation occurs in summer, but with *smaller* amounts when it falls in winter. That is, the effectiveness of winter rain is greater than that of summer rain, because of less evaporation in the cooler season. The contrasted extent of forest and of steppe toward regions of less rain appears in the figure. The recognition and evaluation of the difference in effectiveness of precipitation under different seasonal distributions must be reckoned as one of the greater achievements of the Köppen classification.

[10] See below, in the discussion of the types within the larger temperature groups of the rain or forest climates, *C* and *D*.


Mean Annual Temperature in Degrees Fahrenheit
25° 30° 35° 40° 45° 50° 55° 60° 65° 70° 75° 80° 85°
BWk
BWh
BSk
BSh
Mean Annual Precipitation in inches
0 5 10 15 20 25 30

a. Dry climates with precipitation uniformly distributed through the year.

b. Dry climates with seasonal precipitation in winter of the respective hemisphere.

c. Dry climates with seasonal precipitation in summer of the respective hemisphere.

Note: The figure enclosing the number designates the continent in which the station is located: ⌓ Africa; △ N. America; ▽ S. America; □ Australia; ○ Europe; ◇ Asia.

Fig. 10. Differentiation of the dry (*B*) climates under various régimes of seasonal distribution of precipitation.

In figure 10, the three types of seasonal distribution are separated into as many drawings. A number of stations[11] from the several continents are plotted in their appropriate positions, including some from the drier margins of the forest climates. In figure 10*a*, which represents the climates having a uniform distribution of precipitation through the year, most of the stations are from the higher latitude steppes and deserts, adjacent to the boreal forest climates. The greater number of them therefore belong to the groups of the dry climates with cold winters, *BSk* and *BWk*. The stations represented in figure 10*b* are from the dry margins of the areas having the Mediterranean rainfall régime, and show less wide scattering with respect to temperature. The coldest of the stations plotted is from northern Nevada. The stations with rainfall in the summer of their respective hemispheres (fig. 10*c*) are largely from the tropical steppes and deserts, and so fall within the groups of the hot, dry climates, or in the warmer margin of the cold. The tropical stations with tropical latitudes whose temperatures exclude them from the *h* groups have lower temperatures because of elevation (12, Kimberley; 13, Sutherland; 18, Mexico City), or lie adjacent to cold sea water (9, Swakopmund). The coldest stations with this type of distribution are in Asia (24, Leh; 25, Urga). They represent extreme continental conditions with respect to rainfall régime, and it is significant to note that the seasonal pressure contrasts over the Asiatic continents produce rainfall régimes similar to those within the seasonally dry tropical localities, but of course with widely different temperature conditions.

III. SEASONAL DISTRIBUTION OF PRECIPITATION WITHIN THE RAIN OR FOREST CLIMATES

The primary temperature classes of the rain or forest climates, *A*, *C*, and *D*, are subdivided into second-order groups on the basis of the seasonal distribution of precipitation. Figure 11*a* illustrates the basis of the distinction of the types of *A*— (tropical) climates. Two basic types are recognized, *Af*, in which there is no dry season, and *Aw*, in which the dry season is sufficiently long and severe to produce temporarily the effects of aridity. As is seen in the figure, it is a variable relation between the total annual rainfall and the intensity of the seasonal drought, measured by the rainfall of the driest month, which distinguishes the types. The transitional types, in which a heavy

[11] For their names and the numerical values used, see IV, Appendix, of this paper.

annual rainfall overcomes the effect of a dry season, are shown in their relation to the two primary types.

The definition of the subdivisions of the *C* and *D* climates is based upon a comparison of the precipitation in the rainiest and driest months of the colder and warmer seasons. These months are to be conceived, of course, as being representative of their respective seasons. The seasonal contrast is arrived at by means of a ratio between the precipitation of two typical months of the warmer and cooler seasons.

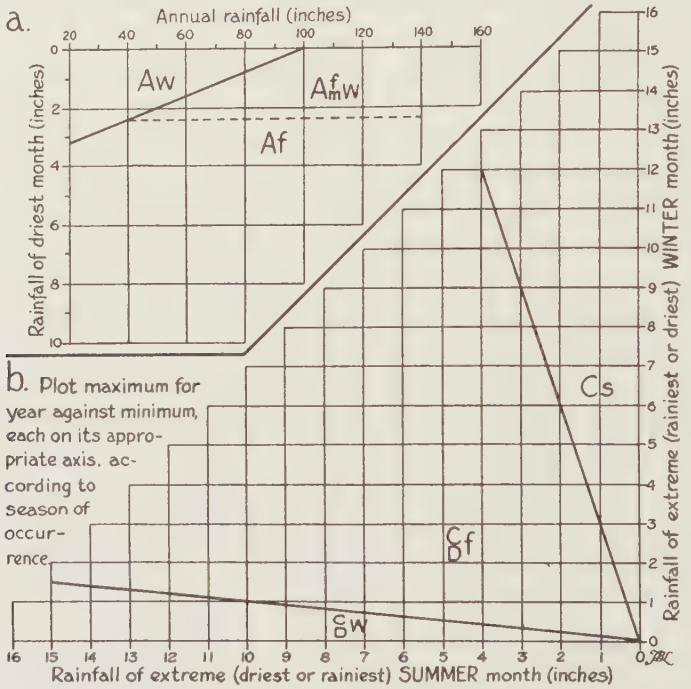

a.
Annual rainfall (inches)
20 40 60 80 100 120 140 160
Rainfall of driest month (inches)
Aw
Af
Afw
b. Plot maximum for year against minimum, each on its appropriate axis, according to season of occurrence.
Cs
Cf
Cw
Rainfall of extreme (rainiest or driest) WINTER month (inches)
16 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0
Rainfall of extreme (driest or rainiest) SUMMER month (inches)

Fig. 11. Subdivision of the rain or forest climates according to seasonal distribution of precipitation.

The same ratio cannot be used for the two cases (*s* type and *w* type), because of the qualifying effect of temperature through evaporation. In the case of summer rain and winter drought, the temperature effect is such as to *reduce* the seasonal contrast in available moisture supply. On the other hand, when the precipitation falls exclusively, or nearly so, in the winter season, evaporation dependent upon temperature *accentuates* the seasonal contrast. The lines which divide the fields of the diagram corresponding to the three types represent the critical ratio used by Köppen. For winter drought, a narrow ratio of precipitation is used, *driest (winter) month: rainiest (summer) month* as

1:10. The ratio is widened when, in the case of summer drought, the summer is drier under a given amount of rain than a winter month with the same amount. The ratio of the precipitation amounts is therefore, *driest (summer) month: rainiest (winter) month* as 1:3. Between these values fall the conditions in which the seasonal contrast may be neglected, and whose climates are designated *f*.

The three diagrams (figs. 1, 9, and 11) present the essentials of the classification. Its fundamental lines are drawn by the distinction of the eleven basic types. These are all represented in the diagrams named. In addition, some of the subtypes and variants of the fundamental types are included where the data for their characterization could be introduced into the figures. Many of the lesser groups, and minor variants, not mentioned here, are qualitative in their definition, and so do not lend themselves to a graphic representation. It is believed that the diagrams make the classification more readily available for whatever use it is to be employed: as a means for the apprehension of the climatic structure of the earth, for the orientation of the climate of a particular locality within the field of variation for the entire earth, for comparative studies such as are suggested in the series of figures for the continents, or as a means for the drawing of climatic boundaries in more detail than is used in the original map of the climates of the earth. In addition, the figures form an adequate basis for a critique of the system since stations whose characteristics are known may be entered in the diagrams and by their actual relations to the system test its accuracy. The quantitative definitions of the various types may have to be changed in time: the need and the direction of the change may be learned from the manner in which stations are grouped in accordance with the existing definitions. No critique is offered here and no comments upon the grouping of stations which appear in the drawings. Modifications or corrections of the classification which are suggested to the reader will render it only more useful, and will be strictly in harmony with the purposes aimed at in its original delineation.

APPENDIX

The values used in the preparation of the temperature diagrams for the individual continents and for the dry climates, were largely taken from Appendix, Köppen's *Die Klimate der Erde,* where is given the largest list of stations with climatic data available in such form. These were supplemented by data from the original 1918 article, from W. G. Kendrew's *The climates of the continents,* and from Bulletin W of the United States Weather Bureau.

In the outline of the field of the variation in temperature of the entire earth (see fig. 1), the values used are those given by Köppen in the 1918 paper, page 244.

Values Used in the Temperature Diagrams for the Individual Continents

(The two values are, in order, the mean temperature of the warmest month, and that of the coldest month, in degrees Fahrenheit.)

Figure 2, Asia—

1. Colombo: 84.7, 76.1
2. Calcutta: 85.6, 65.1
3. Singapore: 81.5, 78.3
4. Mosul: 93.4, 44.6
5. Ispahan: 82.0, 32.4
6. Jacobabad: 97.7, 53.4
7. Leh: 62.6, 17.2
8. Samarkand: 77.0, 31.1
9. Omsk: 67.5, —4.9
10. Lukchun: 72.7, 4.5
11. Smyrna: 80.2, 45.7
12. Delhi: 92.1, 57.9
13. Srinagar: 73.0, 30.7
14. Hongkong, 81.7, 57.7
15. Peking, 78.8, 23.5
16. Kioto: 79.2, 36.3
17. Vladivostok: 69.4, 4.8
18. Blagoveshchensk: 70.3, —13.7
19. Yakutsk: 66.6, —46.5
20. Verkhoyansk: 59.7, —58.9
21. Krasnoyarsk: 66.9, —3.6
22. Mouth of the Lena: 23.7, —36.4
23. Mustag Ata Peak (comp.): 6.8, —50.8
24. Przewalski Mts. (comp.): —4.0, —61.6
25. Mt. Everest (comp.): —9.4, —41.8
26. Novaya Zemlya: 38.1, —3.6

Figure 3, North America—

Extremes:

a. Mohawk Summit, Arizona: 97.9, 50.7
b. Fort Good Hope, Mackenzie: 60.1, —33.3
c. Rocky Mts., Lat. 50° N. (comp.): 17.6, —31.0
d. Point Reyes, California: 56.1, 49.2

Other stations:

1. Martinique: 80.6, 75.7
2. Havana: 81.9, 70.3
3. Colon: 80.1, 79.2
4. Guatemala City: 68.0, 61.3
5. Mexico City: 64.9, 53.4
6. El Paso: 80.4, 44.1
7. San Diego: 68.7, 54.0
8. Yuma: 91.0, 54.7
9. Fresno: 81.9, 45.9
10. Pikes Peak: 39.7, 2.7
11. Salt Lake City: 76.3, 28.9
12. Helena: 66.9, 19.9
13. Calgary: 60.3, 12.9
14. Edmonton: 61.7, 6.4
15. Jacksonville: 81.0, 54.0
16. Savannah: 80.4, 49.8
17. Washington: 76.8, 32.9
18. New York: 73.6, 32.9
19. Boston: 71.2, 27.0

20. New Orleans: 81.3, 53.1
21. Vicksburg: 80.4, 46.9
22. St. Louis: 79.2, 30.9
23. Indianapolis: 76.5, 28.2
24. San Francisco: 59.4, 49.5
25. Portland: 66.4, 39.0
26. Sitka: 54.7, 30.2
27. Buffalo: 70.2, 24.1
28. Chicago: 72.3, 23.7
29. St. Paul: 72.1, 11.7
30. Bismarck: 70.2, 6.6
31. Halifax: 64.8, 21.9
32. Port Arthur: 62.1, 4.8
33. Dawson: 60.3, —24.2
34. Lady Franklin Sound: 37.4, —41.8

Figure 4, Europe—

Extremes:

a. Malaga: 79.0, 54.7
b. Uralsk: 73.8, 6.4
c. Bogoslowsk: 62.6, —2.6
d. Sonnblick: 33.6, 6.6
e. Shetlands: 52.9, 38.3

Other stations:

1. Odessa: 72.7, 25.3
2. Astrakhan: 77.9, 19.0
3. Orenburg: 70.9, 3.4
4. Seville: 84.9, 52.3
5. Madrid: 75.7, 39.7
6. Lisbon: 70.2, 49.3
7. Naples: 75.6, 46.8
8. Milan: 74.8, 32.4
9. Athens: 80.6, 48.7
10. Belgrad: 70.9, 29.3
11. Geneva: 67.1, 32.0
12. Vienna: 67.3, 28.9
13. Hamburg: 62.4, 31.5
14. Breslau: 65.7, 29.1
15. Brest: 64.2, 43.3
16. Dublin: 60.3, 41.5
17. Monach, Hebrides: 55.0, 41.0
18. Stockholm: 62.1, 25.7
19. Warsaw: 65.8, 25.9
20. Kola: 54.9, 11.8
21. Kazan: 67.5, 7.2
22. Ekaterinburg: 63.1, 2.3
23. West Coast Spitzbergen: 40.3, —3.6

Figure 5, South America—

Extremes:

a. Bolivar, Colombia: 83.3, 79.0
b. Piura, Peru: 82.4, 71.8
c. Pilciao: 81.7, 49.6
d. Gallegos: 56.7, 30.6

Other stations:

1. Bogota: 58.6, 57.0
2. Cracas: 72.5, 66.6
3. Georgetown: 81.1, 78.4
4. Cayenne: 81.1, 78.4
5. Quito: 55.0, 54.3
6. Para: 79.7, 77.0
7. Iquitos: 80.4, 77.4
8. Sao Paulo: 71.1, 57.6
9. Callao: 70.9, 62.4
10. Lima: 73.4, 60.6
11. Misti Peak (comp.): 21.4, 13.5
12. Iquique: 70.7, 60.8
13. Santiago: 67.5, 45.9
14. San Luis: 76.1, 48.9
15. La Paz: 52.7, 44.1
16. Cordoba: 73.2, 49.8
17. Buenos Aires: 73.6, 50.2
18. Porto Alegre: 77.0, 56.3
19. Montevideo: 71.6, 50.7
20. Valparaiso: 63.5, 52.7
21. Valdivia: 61.0, 45.0
22. Evangelistas: 48.0, 38.3
23. Punta Arenas: 52.0, 33.6

Figure 6, Africa—

Extremes:

a. Zinder, French West Africa: 91.6, 81.0
b. Berbera, British Somalil: 97.3, 76.1
c. Ghardaia, Algeria: 93.0, 47.1
d. Geryville, Algeria: 78.4, 38.8

Other stations:

1. Lagos: 82.0, 75.7
2. Wagadugu: 88.5, 74.7
3. Sao Thome: 79.2, 74.5
4. Brazzaville: 80.6, 72.3
5. Beira: 80.8, 68.9
6. Mombasa: 81.9, 75.7

7. Fort Johnston: 82.0, 68.0
8. Addis Abeba: 63.5, 56.8
9. Gabes: 81.3, 50.9
10. Biskra, 89.4, 51.1
11. In Salah: 97.7, 54.0
12. Timbuktu: 95.0, 70.5
13. Alexandria: 78.8, 57.4
14. Massaua: 95.2, 78.6
15. Swakopmund: 63.1, 54.5
16. Windhoek, 73.4, 56.3
17. Kimberley: 75.0, 48.7
18. Sutherland: 64.9, 39.2
19. Salisbury: 68.5, 55.9
20. Johannesburg: 65.3, 48.2
21. Cape Town: 69.3, 54.0
22. Algiers: 77.5, 53.4

Figure 7, Australia—

Extremes:

a. Albury: 75.2, 45.3
b. Goulburn: 69.4, 43.2

Other stations:

1. Wyndham: 90.0, 75.7
2. Port Darwin: 84.4, 74.7
3. Daly Waters: 87.1, 67.1
4. Cape York: 81.7, 76.1
5. Carvarvon: 80.8, 63.1
6. Coolgardie: 77.5, 51.4
7. Eyre: 70.0, 53.8
8. Alice Springs: 85.8, 51.8
9. Bourke: 84.2, 51.4
10. Perth: 75.6, 55.0
11. Albany: 65.5, 52.3
12. Brisbane: 76.1, 57.2
13. Sydney: 71.4, 52.3
14. Adelaide: 74.1, 51.6
15. Melbourne: 67.5, 48.7
16. Hobart: 62.1, 45.7

Figure 8, Oceanic Islands—

Extremes:

a. West Coast Hawaii: 70.2, 67.8
b. Stykkisholm, Iceland: 49.5, 27.1

Other stations:

1. Faeroes: 51.4, 37.8
2. Ponta Delgada, Azores: 71.6, 57.0
3. Madeira: 72.1, 59.4
4. Bermuda: 80.1, 62.1
5. Las Palmas, Gran Canaria: 73.8, 62.8
6. St. Vincent, C. Verde: 79.5, 70.3
7. Fernando Noronha: 78.6, 76.5
8. Ascension: 80.8, 74.1
9. Jamestown, St. Helena: 75.2, 64.9
10. Falkland Islands: 49.3, 36.5
11. Tamatave, Madagascar: 80.6, 68.5
12. Seychelles: 80.2, 77.0
13. Reunion: 78.4, 68.9
14. Mauritius: 79.0, 67.5
15. Unalaska: 50.7, 31.3
16. Honolulu: 77.5, 70.2
17. Guam: 82.2, 77.7
18. Ponape: 81.1, 79.7
19. Rarotonga: 77.9, 68.4
20. Auckland, New Zealand: 67.3, 52.0
21. Hokitika, New Zealand: 60.3, 44.8
22. Campbell Island: 49.5, 38.7

In figure 10, the values as plotted on the coördinate field are for first, mean annual temperature and, second, mean annual precipitation. In the following, the values for temperature are given first, in Fahrenheit degrees, and, second, the values for precipitation, in inches:

Figure 10a, Dry climates with uniform seasonal distribution of precipitation: f type régime—

1. Lima, Peru, 66.2, 1.8
2. San Luis, Argentina: 62.4, 21.2
3. Ushuaia, Argentina: 39.9, 21.5
4. Bahia Blanca, Argentina: 58.1, 20.8
5. El Paso, Texas: 64.2, 9.4
6. Yuma, Arizona: 72.1, 3.1
7. Calgary, Alberta: 37.4, 16.2
8. Winnipeg, Manitoba: 34.9, 20.7
9. Bismarck, North Dakota: 40.0, 17.4
10. Denver, Colorado: 49.7, 14.1

11. Ogden, Utah: 50.0, 14.7
12. Boise, Idaho: 50.6, 13.3
13. Broken Hill, N. S. W.: 64.7, 9.3
14. Odessa, Russia: 49.3, 16.1
15. Kiev, Ukraine: 44.2, 21.1
16. Saratov, Russia: 42.1, 14.9
17. Astrakhan, Russia: 48.9, 5.9
18. Orenburg, Russia: 37.9, 15.2
19. Irgis, Siberia: 41.0, 6.7
20. Kashgar, Chinese Turkestan: 54.3, 3.5
21. Semipalatinsk, Siberia: 36.5, 7.3
22. Tomsk, Siberia: 30.2, 19.9
23. Irkutsk, Siberia: 31.3, 14.5

Figure 10b, Dry climates with winter rain, summer drought: s type régime—

1. Tripoli, Libya: 67.5, 16.1
2. Biskra, Algeria: 69.3, 7.1
3. Mogador, Morocco: 63.7, 13.0
4. Marrakesh, Morocco: 67.3, 9.4
5. Ghardaia, Algeria, 68.9, 3.9
6. Cape July, L. de Oro: 64.9, 3.9
7. St. Vincent, C. Verde: 74.5, 7.5
8. Port Said, Egypt: 68.9, 3.1
9. Cairo, Egypt: 70.2, 1.2
10. Cape Town, South Africa: 61.5, 25.6
11. C. Agulhas, South Africa: 60.6, 15.7
12. Las Palmas, Gran Canaria: 67.8, 11.4
13. Santa Cruz, Teneriffe: 67.6, 12.2
14. Iquique, Chile: 66.1, 0.05
15. Santiago, Chile: 55.6, 14.4
16. Valparaiso, Chile: 57.7, 19.6
17. Winnemucca, Nevada: 48.5, 8.7
18. Los Angeles, California: 60.3, 15.6
19. Fresno, California: 63.2, 10.0
20. Sacramento, California: 59.6, 19.4
21. Alice Springs, N. T., Australia: 64.4, 9.2
22. Geraldton, West Australia: 66.5, 17.8
23. Madrid, Spain: 55.9, 16.6
24. Zaragoza, Spain: 57.4, 12.2
25. Saloniki, Greece: 60.4, 17.1
26. Bagdad, Irak: 71.3, 9.0
27. Samarkand, Turkestan: 55.8, 12.6
28. Maskat, Oman: 80.1, 5.1

Figure 10c, Dry climates with summer rain, winter drought: w type régime—

1. Zinder, French West Africa: 81.9, 27.6
2. Banana, French Equatorial Africa: 77.9, 28.7
3. Delagoa Bay, Mozambique: 72.0, 27.2
4. Timbuktu, French West Africa: 84.6, 8.3
5. St. Louis, French Equatorial Africa: 74.1, 16.5
6. Khartoum, Egypt, Sudan: 83.8, 5.1
7. Berbera, British Somalil: 84.9, 2.4
8. Swakopmund, Southwest Africa: 59.2, 0.8
9. Windhoek, Southwest Africa: 66.7, 15.0
10. Springbok, Cape of Good Hope: 62.1, 8.7
11. Kimberley, South Africa: 63.3, 19.7
12. Sutherland, South Africa: 52.3, 9.8
13. Bulawayo, South Rhodesia: 65.7, 22.0
14. Pretoria, Transvaal: 62.1, 26.0
15. Mollendo, Peru: 64.9, 0.8
16. Antofagasta, Chile: 65.5, 0.2
17. Mexico City: 59.9, 23.1
18. Zacatecas, Mexico: 59.0, 22.8
19. Cloncurry, Queensland: 76.9, 20.0
20. Alice Springs, N. T., Australia: 69.7, 11.1
21. Karachi, Sind: 77.5, 7.5
22. Jacobabad, Sind: 79.3, 4.7
23. Leh, Kashmir: 40.8, 3.2
24. Urga, Mongolia: 27.7, 7.1

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CLIMATES OF CALIFORNIA

BY
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PREVIOUS STUDIES

In 1915 W. G. Reed[1] published an analysis of California climates, recognizing two "provinces," three "districts," and seven "regions." These were defined partly by quantitative terms and were mapped on a base without local points of reference other than the State boundaries (scale 1:10,500,000).

This study has been of considerable importance as proceeding from the distribution of climatic elements to a synthesis of climatic areas. The classification of Reed is somewhat limited, however, by the fact that its definitions were made only for the area in mind, that is, for the western United States, while climatic data have accumulated to such an extent that it should be possible to place local climates in a general climatologic system. Moreover, the areal subdivisions of Reed are not consistently based on quantitative terms. The major "provinces," the "Pacific" and "Rain Shadow" areas, are not distinguished on the basis of any definite temperature or precipitation values, or regimens.

The Pacific Province has "generally mild temperatures; marked subtropical winter maximum of rainfall, summers dry or with light cyclonic rains, except in the mountains where summer thundershowers may occur." The "Rain Shadow Area" is characterized by "deficient precipitation, especially when compared with the same latitude west of the mountains." The two "districts" of the "Pacific Province," the "Oregonian" and the "Californian," are separable on the basis of summer rainfall, but not on any stated quantitative basis. The "regions," as, for example, those of the "Californian

[1] "Climate of Western United States," Bull. Am. Geog. Soc., vol. 47 (1915), p. 9.

District," are defined more precisely, the principal criteria being mean annual rainfall and length of summer drought. The propriety of using mean annual rainfall, however, is, in general, open to question.

It is certain that Reed arrived in the main at a true recognition of areal differentiation of climate. His map did provide, as he had hoped, divisions which "seem to be more logical and of greater practical value for the description and study of this portion of the country than any of the previous groupings." But for comparative studies, in which other parts of the world are considered, the system is not well adapted nor does it fully recognize the extent of climatic range that is developed in this State.

Though not based directly on climatologic data, biotic and soil maps indicate distributional facts so intimately associated with climate that they are in themselves close approaches to climatic maps. The life-zone maps and cross-sections of Grinnell[2] (which are based on the life-zones of C. Hart Merriam) are so closely related to climatic values that a representation of California climates by the use of only four types would give approximately the same results as Grinnell's map of life-zones. The soil classifications of C. F. Shaw and associates, based on color contrasts originally, are also essentially expressions of soil genesis correlated with climatic differentiation.

CLIMATIC REGIONS OF KÖPPEN

In this paper the attempt is made to give as full an areal analysis of California climates as present data warrant, expressing the facts of distribution strictly in accordance with a well recognized, widely accepted, quantitative plan, heretofore used principally in a world-wide classification of climates.

The classification followed, and to some extent adapted, is that of Wladimir Köppen,[3] which has acquired wider acceptance than any other. Examination of the climatologic data at hand indicated that somewhat more detail was desirable than was provided by Köppen

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[2] "Distributional List of the Birds of California," Cooper Ornith. Club, Pacific Coast Avifauna, No. 11 (1915), pls. 1, 2.

[3] Die Klimate der Erde (Berlin, 1923). Recently presented in graphic form by Leighly, Univ. Calif. Publ. Geog., vol. 2 (1926), pp. 55–71, 11 figs. in text. Two reviews of Köppen's earlier statement of his classification have appeared in English: R. De C. Ward, in Geog. Rev., 1919, pp. 188–191, and P. E. James, in Monthly Weather Rev., 1922, pp. 67–72. The reader is referred to these references for a statement of the general plan.

for this section. Indeed, for northern Europe, the scene of his more intensive studies, he himself introduced a more elaborate classification than he had employed for parts of the world which he had studied less. Accordingly, a few minor changes have been made in the critical values used, and four new subtypes have been introduced.[4]

The climatologic data used in the construction of the map were derived from reports from more than two hundred stations, in particular those given in the most recent issues of the Sectional Summaries (13, 14, 15, and 16) of the United States Weather Bureau. Only a very few stations, in most cases with short records, are inconsistent with the areas in which they have been mapped. Where information is wanting as to precise climatologic data, particularly in desert and mountain areas of the State, the lines have been drawn or extended on the basis of personal judgment, since with these remoter parts of the State the writer has an acquaintance which may perhaps be regarded as sufficient for these purposes.

CLIMATIC TYPES

Bases of Differentiation of Dry and Humid Climates

Of primary importance in the Köppen classification for California is the distinction between Dry (*B*) climates and Humid (*C* and *D*) climates. The criteria used in making this distinction are mean annual precipitation, mean annual temperature, and seasonal distribution of precipitation. The values used are those set forth in a graph by Leighly.[5] In general the principles involved are the higher duty of winter precipitation as against summer precipitation and the higher duty of a given amount of annual precipitation with low temperatures as against high temperatures. Thus, under the winter rainfall régime prevalent in California, the boundary between Dry and Humid areas lies along the isohyet of 14 inches when the mean annual temperature approximates 55° F. When the evaporation rate is increased with higher temperatures higher rainfall values are

[4] The author has conferred freely with J. Grinnell, C. O. Sauer, and W. A. Setchell, all of the University of California, regarding additions and restatements of climatic values, as well as regarding the interpolation of climatic limits where instrumental data are lacking. The members of his 1926 class in the Geography of California cooperated in tabulating and classifying climatologic data.

[5] *Op. cit.*, fig. 9.

demanded. Thus with a mean annual temperature of 70° F. the boundary is shifted to an isohyet of approximately 17 inches.

Two main subdivisions of Dry, *B*, areas, Desert, *BW*, and Steppe, *BS*, are recognized by Köppen. The relationship between these is similar to the relationship between Dry and Humid climates, and is also represented on Leighly's graph. At the mean annual temperature of 55° F., places receiving between 9.5 and 14.0 inches are classed as Steppe, *BS*, those receiving less than 9.5 inches as Desert, *BW*. At 70° F., Desert areas may receive as much as 13 inches of precipitation.

Of secondary importance in the subdivision of Dry, *B*, climates is the recognition of temperature differences. In the Köppen system two main types are recognized, Hot, *h*, and Cold, *k*. For the dividing line between these types the mean annual isotherm of 18° C. (64.4° F.) is used. Thus there are four main climates in the Dry, *B*, areas: Cold Steppe, *BSk*, and Cold Desert, *BWk*, on the poleward side of the mean annual isotherm of 64.4° F., and Hot Steppe, *BSh*, and Hot Desert, *BWh*, on the equatorial side.

The wisdom of selecting a mean annual isotherm in order to subdivide climate is open to question. In humid climates Köppen has selected either warmest or coldest month temperatures as his principal criteria of subdivision. Boundaries thus obtained are highly satisfactory from a geographic viewpoint. Plant and animal distributions are very frequently outlined by such lines, though controlling factors of distribution may depend upon the temperature of the month during which reproduction takes place rather than upon the temperature of the warmest or coldest month itself.[6]

In Humid climates one of the most important boundaries recognized is that which separates regions of cold winters, Microthermal, *D*, climates, from those having cool winters, Mesothermal, *C*, climates. The isotherm of the coldest month is used in making this distinction and has been so selected that, practically, the areas on the poleward side of the line experience at least a month in which the ground is frozen annually while those toward the equator are free from any such interval of recurring freezing conditions. From a geographical viewpoint this criterion is eminently satisfactory.

It appears that the use of a cold month isotherm as a climatic boundary is just as applicable in Dry as in Humid climates. This

[6] Setchell, W. A., "Temperature and Anthesis," Am. Jour. Botany, vol. 12 (March, 1925), pp. 178–188; also "Stenothermy and Zone-Invasion," Am. Naturalist, vol. 54 (Sept.-Oct., 1920), pp. 285–397.

boundary between Microthermal, *D*, and Mesothermal, *C*, climates may well be extended across Dry areas as the line of separation between Hot, *h*, and Cold, *k*, types. Thus may be eliminated a certain weakness of the original Köppen system, namely, the change from a cold month isotherm to a mean annual isotherm in passing from Humid to Dry areas.

In eastern California and in Nevada the January isotherm of 32° F. seems to indicate a more important climatic break than does the mean annual isotherm of 64.4° F. In general the tree yucca (*Cleistoyucca arborescens*) grows south of this line while junipers (*Juniperus californica* and *utahensis*) grow north of it. "Buried Range" topography, produced by extreme mechanical weathering and most characteristic of the Mojave Desert, will, in general, be found increasingly well developed south, but not characteristic north, of this line. The 32° F. January isotherm similarly separates the portion of the Great Basin characterized by large Pleistocene lakes from a southern portion in which such features were absent, or at least present only in minor degree. From the standpoint of culture we note that people living north of this line, in providing against winter cold, have more carefully constructed houses as a rule and that an important part of the yearly routine, particularly as far as the rural population is concerned—and most of the population is rural—is an annual migration to the mountains in order to cut wood for the following winter.

For the above reasons the January isotherm of 32° F. has been adopted as separating Dry Cold, *Bk*, from Dry Hot, *Bh*, climates. The effect of this selection, as compared with the use of the mean annual isotherm of 64.4 F., is to move the boundary slightly farther north. In general the same change for the whole of the northern hemisphere has the same effect, and may be desirable as a slight modification of the Köppen system.

THE DRY CLIMATES—

While the above subdivision of Dry climates into four types—only three of which appear in California, namely, *BWh*, *BSh*, and *BSk:* Mojave Desert, Mojave Steppe, and Great Basin Steppe areas essentially—seems to identify major conditions, it also appears desirable to introduce a minor subdivision of the Hot Desert, *BWh*, climate in order to differentiate between Mojave and Colorado types. Plant and animal distributions indicate the desirability of this dis-

tinction. Abrams[7] shows a differentiation of plant assemblages for the two areas. At higher levels the most important vegetational difference, at least from the standpoint of landscape, is the replacement of the Mojave *Cleistoyucca arborescens* by the Colorado *Agave deserti*. Dune sand accumulations are more widespread in the Colorado Desert than in the Mojave. Double-roofed houses, arcaded sidewalks, and other cultural evidences of hot weather are more common in the Colorado than in the Mojave. That the distinction between the two is not as important as that between Hot and Cold Desert climates is probably best shown in the mapping of the vegetation of the desert by Shantz,[8] who differentiates between "Sagebrush (Northern Desert Shrub)" and "Creosote Bush (Southern Desert Shrub)" practically along the January isotherm of 32° F., but who maps both Mojave and Colorado deserts in the same, southern, group.

Köppen's mean annual isotherm of 64.4° F. could probably be used as the basis of differentiation between the two hot desert types. A more satisfactory criterion appears to be the line separating areas having three months, or more, with mean maximum temperatures above 100° F. from those lying below such limits. All the Colorado Desert stations fit either definition. It seems probable that the fact of three months with mean maximum temperatures averaging 100° F., or over, is more significant than the fact of the mean annual temperature. The Köppen symbol *BWh* is here used for the Mojave type of Hot Desert and the symbol *BWhh* is introduced for the Colorado type.

The rainfall of the Mojave Desert has a distinct winter maximum, *BWhs*, while that of the Colorado shows, in addition, a secondary maximum in the summer. Thus the rain falling in the Colorado Desert is less effective in general, and ordinarily similar amounts of rain will be expressed by more arid landscapes in the Colorado region than in the Mojave.

Using the definitions given above, the greater part of the San Joaquin Valley is mapped as Hot Desert, Mojave Type, *BWh*. Differences in landscape between the San Joaquin Valley and the Mojave Desert are certainly not attributable to climatic causes but for the most part are edaphic. Shantz[9] maps rather extensive areas

[7] Abrams, Le Roy, "A Phytogeographic and Taxonomic Study of the Southern California Trees and Shrubs," New York Botanical Garden Bull., vol. 6, no. 21 (1910), pp. 320–322.

[8] Shantz, H. L., and Zon, R., "Natural Vegetation," Atlas of Am. Agr., Part I, Section E (1924).

[9] *Op. cit.*

in the San Joaquin Valley as "Greasewood (Salt Desert Shrub)." The Kern Basin falls largely under this heading. Excepting a strip of "Marsh Grass" along the river, "Salt Desert Shrub" represents the lowland condition prevalent as far north as the middle of Merced County. Reed's[10] "Tulare Region" practically duplicates the San Joaquin *BWh* area shown on the accompanying map. His "Tulare Region" is limited by the isohyet of 10 inches, according to definition, and is characterized by "climatic conditions . . . . in many respects like those of the desert region on the south and southeast side of the mountains . . . . except that summer rains, sometimes of a torrential type, 'cloudbursts,' are not common enough to make the curves of average rainfall resemble those of the desert." Reed also calls attention to the fact that much of the drainage of the "Tulare Region" does not reach the sea. The climate of Bakersfield and the southwestern end of the valley approaches closely the Colorado, *BWhh*, type. If this type were defined on the basis of a mean annual temperature greater than 64.4° F., it would include most of Kern Basin. As the area falls short, by a small margin, of the requirement of three months with a mean maximum temperature of 100° F., or more, it has been mapped as *BWh*.

Surrounding the Hot Deserts, is the Hot Steppe, *BSh*, area, the climatic transition between the nuclear areas of the Dry regions and the surrounding Humid climates. For the most part it is mapped as "Bunch Grass" by Shantz. The Salinas Valley, the San Benito Valley, and the Coast Ranges west of the San Joaquin Valley fall into this subdivision primarily because of rain shadow conditions produced by higher areas toward the west. In southern California, where the frequency of rain-bringing cyclonic storms is less than farther north, Hot Steppe, *BSh*, is the normal condition of the lowlands. Coastal lowlands pass from steppe to desert in the vicinity of San Diego. As the annual precipitation decreases in a southerly direction along this coast the amount of foggy weather increases, on the average. The type of desert which appears near San Diego is a border type transitional to the true west-coast foggy desert, *BWhn*, which occurs some distance down the peninsula of Baja California. It is probable that further work will necessitate the recognition of at least three subdivisions of this foggy desert and also that farther to the north it will be recognized that the coastal steppe areas include subtypes of considerable climatic contrast. It is certain that the

[10] *Op. cit.*, pp. 9, 15–16.

coastal steppe areas depart rather widely from the interior steppes in the matter of foggy weather and relative humidity. Unfortunately data are not at hand in sufficient quantities to justify at this time more detailed differentiation of the coastal conditions.

Near the northern border of the State there is a small rain shadow area in the vicinity of Montague, which receives so little precipitation that it falls into the Steppe subdivision of the Köppen scheme. This area is on the border of *BSk* and *BSh* and has been so mapped.

Along the eastern side of the Sierra Nevada, near the southern end of Owens Lake and similarly across Owens Valley at the crest of the Inyo Range, from which points they extend northward, are two areas of Cold Steppe climate, *BSk*. This is the climate of most of the northern half of Nevada. Much of the land is covered with sagebrush (particularly *Artemisia tridentata*), with a Piñon-Juniper association, and with scattering bunch grass assemblages. In the *BSk* regions in California the maximum of precipitation occurs in winter (therefore separated as *BSks*). Here a considerable snowfall is to be noted, but everywhere in this climatic subdivision occasional cloudbursts and thunder storms bring rain or hail at other seasons.

MESOTHERMAL CLIMATES—

Two of Köppen's three major types of Humid climate are found in California. They are separable on the basis of temperature.

The warmer humid type, Mesothermal, *C*, is characterized by having the average temperatures of its coolest month between 64.4° F. and 32° F. Köppen uses a value of —3° C. for his poleward limit of Mesothermal, *C*, climates. This value is inapplicable to California, nor need one insist on the strict application of the Köppen value of —3° C. for this boundary, for it is evident that the amplitude of the curve of annual temperature must be taken into consideration. A brief cold period may not be as effective as a somewhat more protracted cold spell of lesser intensity. Where the annual range of temperature is rather small the boundary between Microthermal and Mesothermal climates may be placed somewhat higher on the temperature scale than where the annual range is great. The important difference between the two climates hinges on the question of whether or not the ground is frozen each winter. In California the annual ranges of temperature are not so great as those farther east and the decline of temperatures to their minimum, normally taking place in

January, is gradual, so that one may use the value of 0° C. in place of Köppen's —3° C. for the Microthermal-Mesothermal boundary. It is certain that the 0° C. line is more clearly recognized in California landscapes than is any line based on slightly colder January conditions.

West coast Mesothermal climates are characterized by winter rainfall, *Cs*. Farther toward the poles the amount of rain received during the summer increases, Köppen's *Cf*, but the winter maximum persists. Farther equator-ward summer dryness is more pronounced. The type of Mesothermal climate characterized by at least three times as much rainfall in its wettest winter month as received during its driest summer month is commonly known as "Mediterranean," *Cs*. All the Mesothermal climate in California is of this type. In area "Mediterranean climate" covers about half of the State.

Köppen recognized two types of Mediterranean climate, a hot summer type, "Olive climate," *Csa*, with its warmest month averaging above 71° F., and a cool summer type, "Heather climate," *Csb*, with its warmest monthly average below 71° F. This distinction works out particularly well in California. Citrus fruits are raised, commercially, almost wholly in the *Csa* area, or in adjacent Dry climates. The scattered oaks of the "Park Landscapes" of the *Csa* areas are replaced by closer formations of trees in the *Csb*, often by true forest growth. The short and often bunchy grasses of *Csa* in general grade into taller grasses in close formation toward the nuclear parts of the cool summer areas. Chaparral of the more or less rugged slopes of mountains and hills in the *Csa* region is replaced gradually by tree growth on the more subdued and rounded slopes of centrally situated *Csb* areas. Residual soils deepen in the same transition.

In the Sacramento Valley Hot Summer Mediterranean is the prevailing climate. Eastward from the Carquinez gateway, in the delta lands, the cooling effect of exposure to breezes from the ocean is felt in summer and a considerable part of the delta and its margins is excluded from the *Csa* class. Toward the south the *Csa* temperature and rainfall values gradually disappear from the lowlands and become characteristic of higher regions. As rainfall values diminish toward the south the lowlands more and more become Dry areas, and Humid climates correspondingly are restricted to smaller and smaller highland locations. Though a rather wide range of latitude exists between the Sacramento Valley and the mountains of southern California, it is not sufficient to justify further subdivision of the Hot

Summer Mediterranean, at least in keeping with details supplied elsewhere on the map.

Cool Summer Mediterranean, *Csb,* climate characterizes the Coast Range region of Central California. The lowlands of this area are generally grass-covered, often with scattered oaks covering them in open formation, a park landscape. Chaparral occupies considerable areas in the hills, often grading upward into pine (*P. sabiniana*, and often, *ponderosa*) forest. Relief features are quite generally rounded in general profile, with many scars as the result of slumping and creep. Weathered rock remains on all but the steeper slopes in such quantities that it is likely to obscure the unaltered bedrock. Prominent ledges or surfaces of bedrock, such as become important portions of the average scene in southern California, are present only to a minor degree.

If, with Köppen, we stop in our subdivision of the *Cs* climate with the two types considered thus far, practically all of northwestern California and a rather wide belt extending along the western side of the Sierra Nevada will fall into the Cool Summer, *Csb*, type. It seems undesirable, though, to group together such areas as those about Crescent City and the Upper Kern River in a single climatic type. As a matter of fact Köppen's *Csb* area in California can readily be divided into three parts which differ quite as much from one another locally as does *Csa* from *Csb*.

Along the coast a distinctive climatic type is recognized popularly and is often called the "Fog Belt." The Redwood (*Sequoia sempervirens*), the California Laurel (*Umbellularia californica*), and numerous other trees preferring cool situations characterize the belt. Many of its hillsides are covered with bracken and berries. Because of summer fog the maximum temperature occurs in late August, or even in September, with June often being warmer than July. Very little seasonal change of temperature takes place, a portion of the area having "Isothermal," *Csi*,[11] conditions. Various attempts were made to define this belt. It was found that the most satisfactory definition could be based upon the fact of summer coolness. As mapped the "Fog Belt" represents the area which fulfils the requirements for *Csb* but which, in addition, has no month with a mean temperature of more than 64.4° F. A symbol for this climate appropriate to the Köppen system is *Csn*.

[11] Leighly, *op. cit.*, p. 60.

Landscapes in the Yellow Pine-Douglas Fir forest differ sufficiently from those in other portions of the Mediterranean climate to justify still another subdivision. It was found that the isohyet of .75 inch for the three consecutive driest months forms a satisfactory lower boundary for this forest area. Practically all of the area receiving this quota of summer rain would ordinarily be classed as Cool Summer Mediterranean, *Csb,* and isolated peaks in southern California and a narrow strip along the western side of the northern Sierra Nevada have been subtracted from *Csa* to form the new type. The unification of this area in terms of a sufficient amount of summer rainfall seems to be much greater than any diversification within it based upon summer heat. Köppen does not provide a symbol for this climate, hence *Cs'ab* is added to designate it.

MICROTHERMAL CLIMATE—

Microthermal areas in California are characterized by winter rainfall similar to that of the adjoining Mesothermal areas. The seasonal contrast of rainfall in this area is important, the month receiving the greatest amount always having far more than three times as much as the month receiving the least. Normally the condition of summer dryness is unrelieved by upland snow accumulations. It seems desirable because of this marked seasonal contrast to depart from Köppen's usage and use the symbol *Ds* for the Microthermal area in California.

Although of somewhat questionable value as an indicator type, in California the most characteristic tree of Microthermal areas is probably the Lodgepole Pine (*Pinus contorta*), often incorrectly called Tamarack. On the western side of the Sierra Nevada the Sugar Pine (*Pinus lambertiana*) forest grows partially in Microthermal, *Ds,* and partially in Mesothermal, *Cs'ab* areas. Frost action plays an important part in rock weathering in the mountainous microthermal portion of California. Mechanical weathering also takes place rapidly as a result of great daily ranges of temperature. Occasional torrential showers accompanying summer thunder storms still further increase the similarity between erosional conditions of microthermal and dry climates, accompanying which are certain similarities in landscape, notably the fact of rather steep and angular relief features. It is generally true, however, that the dominant land and drainage forms of Microthermal areas are not those forming at present but are relict features but little changed since the last glaciation of the

area. At present no other part of the United States receives as much snow as do portions of California's *Ds* region. A number of small glaciers are at present active in this area.

TUNDRA CLIMATE—

A narrow strip in the High Sierra and the summit area of Mt. Shasta have been mapped as Tundra, *E*, climate. No stations regularly recording temperatures exist in these areas. This treeless alpine area differs sufficiently from the Microthermal area to justify its being placed in another type and there is little doubt that it meets the Köppen requirement of having all monthly means below 50° F.

Climates of California.

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THE EAST BOLIVIAN ANDES

SOUTH OF THE RIO GRANDE OR GUAPAY

BY

OSCAR SCHMIEDER

INTRODUCTION

My first expedition into Bolivia was undertaken in July, 1924, from La Quiaca, the northern railway terminus of the Argentine Republic. This small town on the Argentine-Bolivian border was especially convenient as a starting point, since a railroad from La Quiaca to Tupiza, and also an automobile road to Tarija, had lately been completed. Thus two new routes into Bolivia were available. Fully as important was the resultant fact that the muleteers, or arrieros, of the northern frontier had in large part lost their occupation, so that mules and men were to be had promptly and most reasonably—a decisive consideration, as these studies were undertaken on my own limited means. That I always had proper animals for mountain travel, and in particular that I had as arriero Martín Maizares of Yavi, to whom all difficulties of the road yielded, was due to the good offices of Don Francisco Thiel of La Quiaca. I traveled always with one pack mule and was accompanied by one mounted arriero.

The first trip took me across the Puna to the valley of Rio San Juan del Oro (fig. 1). This valley is passable only during the dry winter months, since for long distances it is so narrow and the sides so steep that the only path is in the river bed, and the summer floods sometimes cover its whole floor for months at a time. It was my intention to ride down the valley to the Rio Pilaya, but in Escapana I rested in the hospitable house of Doña Mercedes de Campero, who lives upon the remnant of what was considered a century ago the

most extensive and valuable estate of the New World.[1] Doña Mercedes gave me my first knowledge of old ruins nearby, three of which I visited. Thus I lingered in the interesting valley of the Rio San Juan

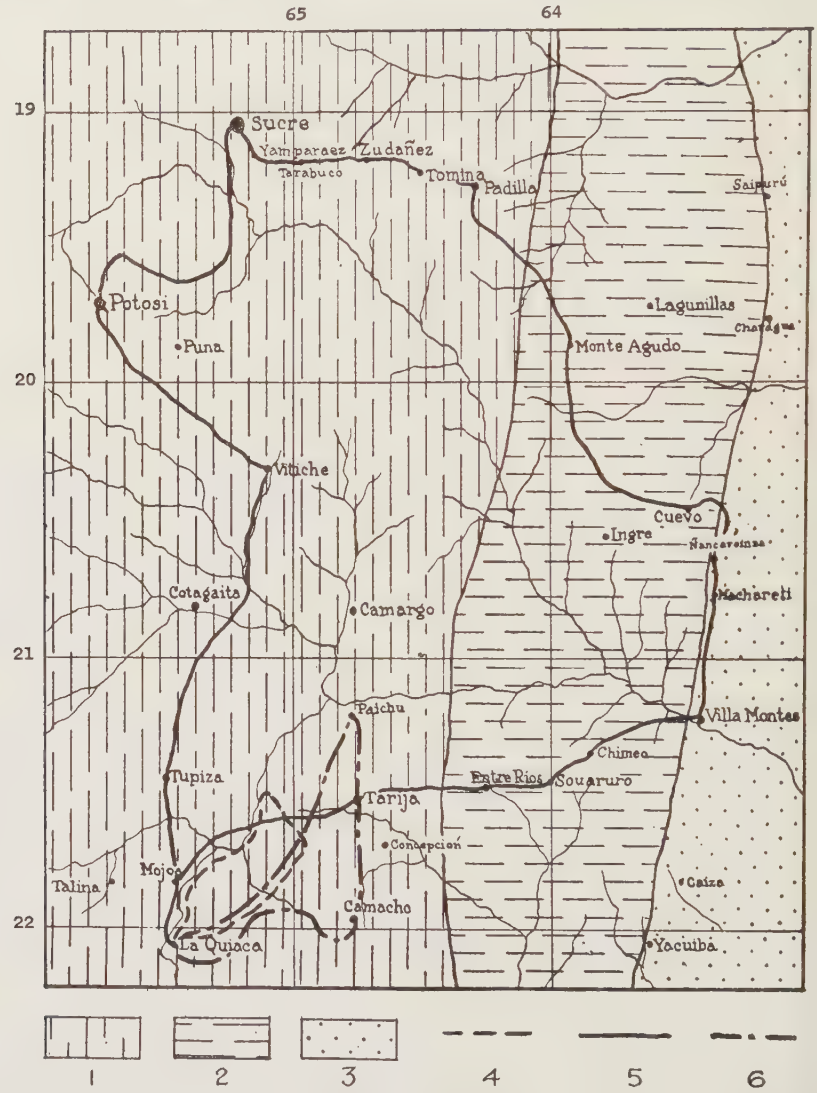

Fig. 1. The main landscapes and the routes of travel. 1, Puna; 2, Front Ranges of the East Bolivian Andes; 3, el Gran Chaco; 4, first trip; 5, second trip; 6, third trip.

del Oro, and finally, ascending the Puna to the east, rode back to La Quiaca on the Tarija road without reaching the Rio Palaya.

[1] Temple, Edmund, Travels in various parts of Peru (1830), vol. 2, pp. 357–364.

On December 1, 1924, I came again to the Argentine-Bolivian border (fig. 1). This time I went straight east from the Puna to the margin of the Chaco and on Christmas Day came to Villa Montes, situated where the Pilcomayo leaves the Andes to enter the Chaco. Here I was the guest of Consul Carl Pflanz, recently come from Buenos Aires to inspect the large estate of Staudt and Company. His interest and training in scientific observation and his long experience of life in the Chaco enabled him to give me many useful suggestions. Only a few weeks later he was drowned.

In the closing days of 1924 I rode northward along the eastern front of the Cordillera as far as Boyuhibe. There I turned west and entered the forest-covered mountains of eastern Bolivia. By way of Monte Agudo, Padilla, and Sucre I got to Potosí. Although the mules were in sorry condition we pushed on with very brief stops. The year had been abnormally dry, the harvest was very short, and feed was almost unprocurable. By way of Vitiche and Tupiza we came back to La Quiaca.

After a short rest I started again from La Quiaca on February 15, 1925, with fresh mules. I crossed the Cordilleras of Santa Victoria and Camacho and descended eastward into the valley where the Antigal de Camacho, an Inca outpost in ruins, lies at the base of the steep Puna slope. From there I went to Tarija and on to the north. It was my intention to cross the Rio Pilaya at Cuchipuchro, where an English mining company years ago had tunneled the neck of a meander, diverting the river underground, but an accident sustained a day's march from the prospective terminus forced us to return by the shortest route possible to La Quiaca.

GENERAL VIEW OF THE REGION

Cartographic Status

The region visited, especially the front ranges of East Bolivia south of the Rio Grande, is not represented truly or even approximately in any of the published maps. On most of them the position of the settlements, the courses of the streams, and the forms of the land surface are inaccurate. The large French map, drawn on a scale of 1:750,000 evidently is based largely on hearsay.[2] Important, for

[2] Crequi-Montfort, G. de, and Sénéchal de la Grange, E., Régions des hauts plateaux de l'Amérique du Sud parcourues par la Mission française. Carte dressée par V. Hout (1903).

the eastern Puna, is the itinerary of the expedition of Steinmann–Hoek–von Bistram.[3] The route from Yacuiba, Argentine, to Santa Cruz de la Sierra, Bolivia, has been surveyed by Th. Herzog,[4] and again by Kirtley Mather.[5] These itineraries represent not only the western border of the Gran Chaco but also in pretty exact form the most easterly of the Andean front ranges. The most valuable map of the East Bolivian front is, probably, an unpublished map based on a recent survey made by the Standard Oil Company of Bolivia.

My own itineraries[6] (see map) connect between those of Steinmann to the west and of Herzog and Mather to the east. Together with an unpublished, rough yet valuable, sketch made by the Farquhar Syndicate when a railroad was projected from the Argentine frontier to Santa Cruz de la Sierra, these have been utilized in figure 2 to show schematically the characteristic major forms of the land surface.

Regional Subdivisions

The East Bolivian Andes south of the Rio Grande comprise three great natural landscapes (fig. 1). The normal Puna in the west is long since a well understood geographic concept. Only its eastern border is included in this study. This eastern border may be called

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[3] Hoek, Henry, and Steinmann, Gustav, Erläuterung zur Routenkarte der Expedition in den Anden von Bolivien, 1903–1904, Petermann's Mitt., vol. 52, Heft 1 (1906).

[4] Die bolivischen Kordilleren. Reiseweg von Nordargentinien nach Santa Cruz, Petermann's Mitt., vol. 59 (1913).

[5] Front ranges of the Andes between Santa Cruz, Bolivia, and Embarcación, Argentine, Bull. Geol. Soc. Am., vol. 33, pp. 703–764 (1922): Along the Andean front of southeastern Bolivia, Geog. Rev., vol. 12, pp. 356–374 (1922).

[6] The itinerary contains the following determined points:

La Quiaca (Nat. Observ. of Argentine)	Lat. 22° 6′ 10″	Long. 65° 36′ 16.5″
Villa Montes (by the Bolivian national geodesist, 1924)	Lat. 21° 15′ 36″	Long. 63° 30′ 14″
*Sucre	Lat. 19° 2′ 47″	Long. 65° 17′ 59″
*Tomina	Lat. 19° 11′ 4″	Long. 64° 28′ 15″
*Padilla	Lat. 19° 18′ 23″	Long. 64° 19′ 48″
*Monte Agudo	Lat. 19° 48′ 6″	Long. 63° 54′ 44″
*Cuevo	Lat. 20° 27′ 17″	Long. 63° 32′ 11″
*Machareti	Lat. 20° 48′ 58″	Long. 63° 24′ 29″
*Tarairi	Lat. 21° 5′ 49″	
*Tarija	Lat. 21° 32′ 11″	Long. 64° 45′ 11″

* See Ing. J. B. Vaudry *in* A. Chervin: Anthropologie boliviénne, vol. 1, Publications de la mission scientifique G. de Créqui-Monfort et E. Sénéchal de la Grange (Paris, 1908).

The Sierra de Aguaragüe has been drawn after Herzog; the route from Tarabuco to Sucre after Steinmann. The elevations are obtained by a single Goulier aneroid, but differ largely from the results obtained on identical basis by Steinmann and Vaudry. The figures are therefore given as a rule only to the nearest hundred meters.

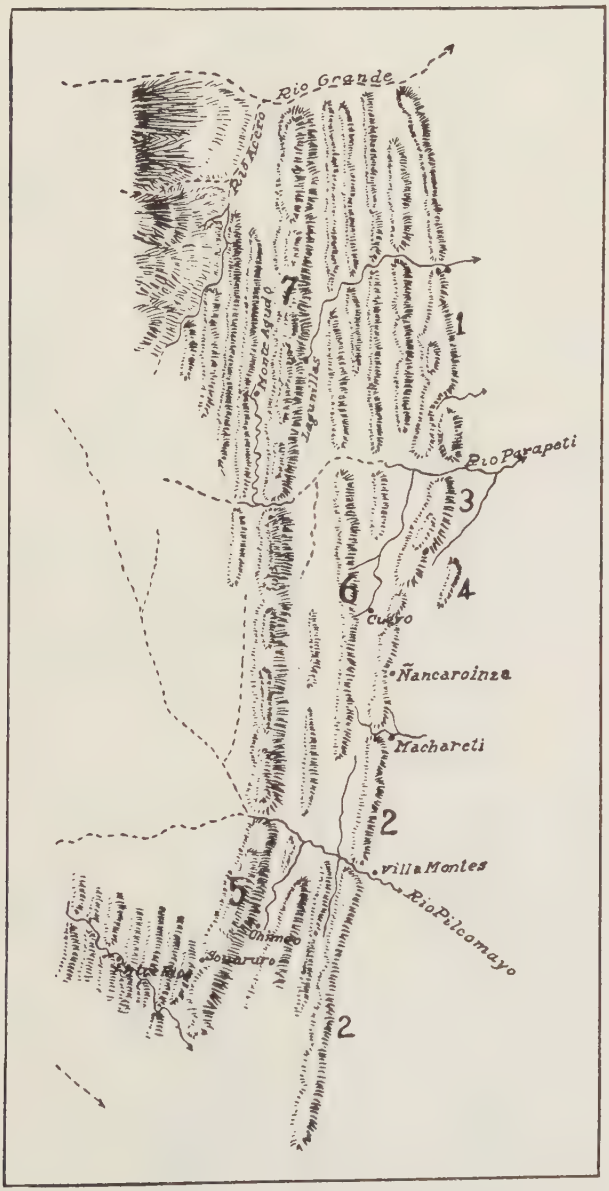


Fig. 2. The Front Ranges of the East Bolivian Andes, 1:2,500,000. 1, Serranía de Charagüa; 2, Serranía de Aguaragüe; 3, Sierra de Tacuarande; 4, Sierra de Toay; 5, Serranía de Souaruro; 6, Sierra de Mandiyuti; 7, Serranía de Incahuasi.

Fig. 3. Cross-section from the Puna to the Chaco.

the *Dissected Puna* in order to distinguish it from the Puna proper on the west, which is still a plateau of interior drainage. The recent dissection of the eastern Puna has developed a characteristic series of geographic features that are wanting in the normal Puna.

The *Gran Chaco,* at the eastern margin of the area studied, constitutes a natural landscape the identity of which is unquestioned, although large parts of it are still unexplored. The Chaco proper was studied only in its western border. Outliers of its surface penetrate into the Andes here and there.

Mather has applied the term *Front Ranges* to the eastern versant of the Andes, for which German geographers have employed the name "East Bolivian *Bergland.*" In both terms lies recognition of the essential difference of this area from the Cordillera proper and from the Puna. The geographic individuality of this area remains to be specified. Not even its limits to the west have been drawn, although they are strikingly apparent. Hettner, for instance, includes in the Bergland large parts of the eastern Puna.[7] The nature of the East Bolivian front ranges in all respects is, however, so different from that of adjacent areas, that its geographic individuality may be established even in a summary sketch.

Contrasts and Connections

The first expedition, from La Quiaca on the plateau of the Puna to the more easterly lowland of the Gran Chaco, made certain of a fundamental geologic contrast between the eastern and western parts of the section traversed (fig. 3, profile A). Lithologically and tectonically the two areas are distinct. Paleozoic rocks constitute the western area in the main. The beds are gently folded, the anticlines still forming the mountain ridges. The synclines are filled with younger (late Cenozoic) deposits. Mesozoic rocks are wanting for the most part. Structurally, therefore, the western area belongs to the Puna. The change occurs along a meridional line not far east of the settlements of Padilla and Tarija (fig. 3, profiles A and B).

Farther east the geologic conditions are quite different. Paleozoic rocks appear only in the very narrow meridional strips, imbedded as *Schuppen* between great blocks of the Puca formation (Mesozoic), which dip, as a rule to the west. Very locally the Paleozoic appears as the core of the vertical folds of the Puca sandstone.

[7] Hettner, A., Grundzüge der Länderkunde, vol. 2, p. 425 (1924).

The Puna surface at the west lies on the average at an elevation between 3300 and 3600 meters and is overtopped by ranges attaining to more than 5000 meters. In the eastern part of the Puna a different structure, especially characterized by many meridional fault lines, is manifested in distinctive land forms. Here numerous hogbacks extend uninterruptedly north and south for hundreds of kilometers. Their scarp faces are directed generally toward the east, the western slopes being largely dip slopes. Even the highest parts of these ridges do not greatly exceed 2000 meters.[8]

The climate of the Puna differs markedly from that of the East Bolivian front ranges. The meridional mountain ranges intercept the major part of the moisture carried by the east winds, which therefore reach the heights of the Puna as rather dry winds. The eastern ranges are covered by dense, moist forests. The Puna is overspread by a widely spaced, stunted growth of shrubs and grass, the Puna steppe.

Man conquered these different landscapes in varied ways. Where eastern Puna and front range meet, geologic, morphologic, climatic, vegetational, and faunistic limits appear also to an extraordinary degree. This striking natural divide coincides with a not less remarkable cultural border line. The highland dwellers were not attracted by the forest lands, which were occupied at a late date by Indians of Guaraní linguistic stock coming from the upper Paraguay.

THE EASTERN PUNA

Structural Basis

The older beds.—Paleozoic rocks form in the main the base of the eastern Puna. They are chiefly argillaceous and arenaceous schists, friable yellowish brown sandstones, and quartzites.[9]

Intensive folding, especially plication, is found only in the Silurian schists (pl. 5*b*), developed especially in the western areas. As a rule the older formations are compressed into upright anticlines and

[8] These ridges are known as *cuestas*. *Cuesta* means 'slope,' not necessarily a 'steep slope,' and is applied in the vernacular to any impressive incline.

[9] They belong to the Cambrian, Silurian, and Devonian, this age differentiation being of little geographic significance. Steinmann, G., and Hoek, H., Das Silur und Cambrium des Hochlandes von Bolivia u. ihre Fauna, N. Jahrb. f. Min., etc., Beilage, vol. 34, pp. 176–252 (1912).

synclines, striking north–south. These folds form a great series of parallel meridional waves, their length varying from a few hundred meters to several hundred kilometers. They die out insensibly as a rule by the flattening of the folds. The anticlines form the so-called "normal Puna ranges" (Steinmann); the synclines, usually filled with débris, form the Puna plain. Locally Paleozoic strata may be found in horizontal position.

The Puca formation.—Only one Mesozoic formation is involved in the composition of the eastern Puna. It consists principally of red, often argillaceous sandstones containing but little of the colored marls which form the striking middle member of the formation in northwestern Argentine, as, for instance, in the Quebrada de Humahuaca. Brackebusch, who became acquainted with the formation in northwestern Argentine, gave it the significant name *formación petrolífera.*[10] For, from the provinces of Salta and Jujuy northward as far as Santa Cruz de la Sierra in Bolivia, a distance of more than 600 kilometers, it contains numerous oil springs. The formación petrolífera contains also beds of salt, which are in part workable. Steinmann later called these sediments the Puca formation, considering that the red color of the sandstones (*puca*, red in Quichua) was more characteristic than the partial presence of oil.[11]

The sediments of the Puca formation occur in the Puna mostly in the form of narrow, meridional synclines, some of which are of most extraordinary length. The most striking of these belts begins in the Quebrada del Toro on Argentine territory, extends thence by way of Rio de Yavi through the valley of the Rio San Juan del Oro (pl. 8*a*),

[10] Estudios sobre la formación petrolífera de Jujuy, Bol. Acad. Nac. Cienc. Córdoba, vol. 5, pt. 2, pp. 136–184 (1883); Viaje a la provincia de Jujuy, *ibid.*, pp. 185–252.

[11] The age of the Puca formation is still uncertain. The only usable evidence appears to be a limestone, intercalated in the middle of the series, which contains brackish water fossils. D'Orbigny locates the formation in the Triassic. Brackebusch (*op. cit.*) considers the lower section, *areniscas coloradas*, to be Lower Cretaceous. Bodenbender (Informe sobre una exploración geológica en la región de Orán, Bol. Min. Agr. Nac. Argent., vol. 4, nos. 4, 5, 1906) identifies the lower sandstones with the *Estratos de Paganzo* or the *serie permo-mesozoica* in Argentine. Steinmann (*op. cit.*) classified the fauna of the limestone horizon as Cretaceous. Schuchert (Am. Jour. Sci., vol. 38, 1914) considers them as "suggestive of Lower Jurassic age." Stanton (*ibid.*) considers the forms unsafe criteria for definite determination of age. Bonarelli (Tercera contribución al conocimiento geológico de las regiones petrolíferas subandinas del Norte, An. Min. Agr. Nac. Argent., Sec. Geol. Min. y Minas, vol. 15, no. 1, 1921) collected perhaps the most ample fossiliferous material and comes to the conclusion that it is of late Triassic or early Jurassic age. Mather (*op. cit.*) accepts Bonarelli's determination of age and calls the calcareous horizon *Vitiacua* limestone, the strata below it the *Bermejo series*, and those above it the *Tacuru formation.*

and still farther north beyond Sucre, a total length of nearly 700 kilometers with a width ranging from several hundred meters to several kilometers (fig. 4).

Fig. 4. Geologic sketch.

The form of this syncline in the Puca is variable. In places both flanks are compressed, in places it is a shallow trough which has been dislocated here and there by overthrusts. As a rule the western flank

has steeper dips than the eastern one (pl. 8*a*). Other similar infolded belts of meridional alignment were crossed between Sucre and Potosi near Betanzos, and on the way from Potosí to La Quiaca near Tuctapari and Tupiza.

The Puca sediments rest upon Paleozoic strata, those in the eastern Puna mostly on Silurian schists. The contacts between the strata are for the most part concordant, though disconformities are evident here and there. The Puca as a rule, however, is less intensively folded than are the underlying slates and schists, which are usually contorted and appear to have been of inferior competence during deformative movements.

The Puna Fill.—The Paleozoic strata and the Puca sediments are beveled across by an old erosion surface, above which lie more recent sediments consisting of poorly coherent brown sandstones and conglomerates, clays, and volcanic tuffs, in variable sequence, having a maximum thickness of several hundred meters (pl. 4*b*). The basal beds are more or less deformed, and were involved in the orogenic movements of the first Andean phase.[12] The upper beds are horizontal or at least without apparent dislocation. Partially equivalent sediments are those known from the Argentine as the Jujuy of Steinmann, the Calchaquí of Bodenbender, and the Puna of W. Penck.[13]

Eruptive rocks.—Of limited local importance in the eastern Puna are young eruptive rocks, such as those near Tupiza and Betanzos, extruded over the Puca sandstones in small flows. Farther west, near Potosí and west of Tupiza, they become sufficiently extensive to have some significance in the landscape. Here they form resistant masses rising conspicuously above the Puna. They are also important as the sources of the metals mined in those areas (pl. 13*b*).[14]

Orogenic history.—The interpretation of these structures gives us in its main outlines a picture of the orogenic history of the area, and of its surficial expression. The common disharmony in the intensity of folding of Paleozoic and Puca beds might suggest a pre-Mesozoic orogenic period for this part of the Andes. The general structural

[12] The thickness of these beds is less in the Puna than in the adjacent parts of the north Argentine Andes: Keidel, Hans, Neuere Ergebnisse der staatl. geol. Untersuchungen in Argentinien, Extra. C.-R. 12 ième Cong. Géol. Intérnat. (Stockholm, 1912); also Schmieder, O., Contribución al conocimiento del Nevado de Chani, Bol. Acad. Nac. Cienc. Córdoba, vol. 27, pp. 142–144 (1923).

[13] Bodenbender, G., Calchaqueño y los estratos de la Puna de Penck, Bol. Acad. Nac. Cienc. Córdoba, vol. 27, pt. 4, pp. 404–468 (1924); Penck, W., Südrand der Puna de Atacama, Abh. math.-phys. Kl. Sächs. Akad. Wiss. (1920).

[14] Steinmann, G., Über gebundene Erzgänge in der Kordillere Südamerikas, Internat. Kong. Bergw. (Düsseldorf), 1910.

accord of the two series at their points of contact, however, suggests a simultaneous folding after the Puca materials were deposited, but a different behavior with reference to the diastrophic forces, as Steinmann indicates.[15] And indeed it seems that the difference in folding is only due to differing competence of the two series. The direction of strike of the Paleozoic folds agrees with the general meridional direction of the major tectonic lines of the Andes, and thus gives further support to the theory of one major diastrophic period.

The folding of Paleozoic and Mesozoic strata is assigned therefore to the first phase of the Andean deformation. Simultaneous volcanic eruptions took place through the Puca strata, the ejecta being widely distributed on the Puna, usually dislocated during the second phase of the Andean movement.

With orogenic disturbance exogenous forces of degradation were set in operation. Denudation proceeded to extend a peneplain across the folded strata, the post-Cretaceous "*Punarumpffläche*" of W. Penck. Only certain strongly developed anticlines resisted the process of leveling and remained as normal Puna ranges.

The degradation of the tectonic heights was accompanied by the filling of the tectonic depressions. Volcanic ejecta contributed largely, their sources mostly outside of our area. Following the incipience of this final sedimentation a second period of diastrophism set in, as recorded by the dislocations in this Puna series. The horizontal components of this second orogenic phase were small as compared to the first; however, the amount of uplift was considerable. On the Cerro de Potosí, at elevations above 4000 meters, the remains of a mid-Tertiary flora have been found in volcanic tuffs, showing all the features characteristic of tropical climate.[16] The flora suggests an uplift of one or two thousand meters. This uplift has been of greatest significance in the development of the present features of the eastern Puna.

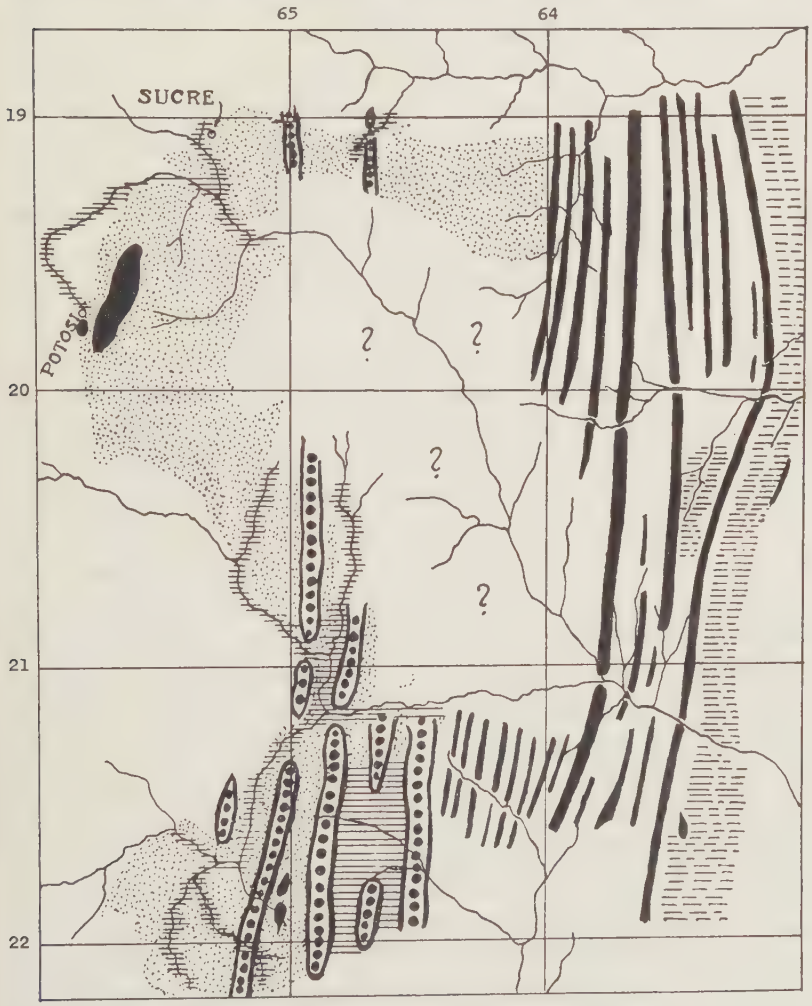
Land Forms

The old peneplain and its origin.—To understand the land forms (fig. 5) of the eastern Puna it is necessary to distinguish clearly two groups of forms, which originated at different times; an older peneplained surface, and forms due to present dissection. The older form group owes its origin to the first orogenic movements in the Andes

[15] Zur Geol. des südöstl. Bolivien. Zentralbl. f. Min. (1904).

[16] Steinmann, Über die junge Hebung der Kordillere, Geol. Rdsch., vol. 13.

and to simultaneously begun processes of denudation, which were able to operate effectively in the subsequent lengthy period of tranquillity. The meridional mountains and depressions, coinciding with anticlines and synclines, are the striking products of early (Tertiary) Andean



High plains of the Puna
Normal Puna ranges (anticlinal)
Mountains of the Puna proper (intruded mass)
Young erosion valleys and structural depressions
Front Ranges
Low plains

Fig. 5. Land forms.

folding. These forms alone resisted the general leveling during the following period of rest in which the minor orogenic unevennesses were wiped out by subaerial denudation. At the end of this period therefore a peneplain had been formed extending through the whole area of the eastern Puna, surmounted wave-like by the higher anticlines of the normal Puna ranges (pl. 3*b*).

The Tertiary Puna peneplain, which cuts across all the smaller folds of the Puna block, constitutes in many places a remarkable element in the landscape (pl. 5*b*). Smaller depressions within it are generally filled with the younger clastic débris, the Puna Fill, their surfaces forming, together with the surface of degradation of the peneplain, the actual Puna Plain, that lies today, mostly a smooth plateau, at elevations for the most part between 3300 and 3600 meters (pl. 3*a*).

The gradational process that shaped the Puna Plain must have taken place under climatic conditions that differed from those of the present day. In the eastern Puna at present the precipitation is sufficiently ample so that the excavations of the structural basins is proceeding primarily through the agency of running water. When the later accumulations (Puna Fill) on the Puna were taking place the precipitation appears to have been more meager. At that time the whole eastern Puna was an area without external drainage, as the western Puna is today. The weathered débris that moved down from the heights was not carried away as it is today by streams; it lodged in the structural depressions and filled them up until the Puna peneplain was partially buried beneath this mantle. The denudation of the heights at that time was balanced by the aggradation of the depressions within the same general area.

The pattern of the land forms of the eastern Puna prior to the second phase of the Andean movements was therefore simple and large as to scale; simpler even than we see it today in the undissected Puna to the west where volcanic forms are added to the ordinary forms of the Puna surface. A single morphologic element brought diversity into this monotonous aspect of the surface, the strata of the Puca formation, then of considerably greater extent than now. The greater part of these beds was destroyed by denudation and their débris was filled into the basin. They were partly preserved by being buried under the younger deposits. Where remnants of them still form parts of the surface they have readily recognized qualities. Usually infolded as synclines into the Paleozoic strata, they are often

morphologically expressed as synclinal or isoclinal valleys (pl. 8*a*). Although they too became a part of the Tertiary peneplain the results were different because of their distinctive lithologic character. The margin of these Puca beds is always a steep escarpment against the older strata. These cliffs of brilliant red sandstone, wherever developed, form a conspicuous landmark in an otherwise monotonous surface.

The extrusive beds, formed in the first period of diastrophism, have but little influence on the land forms of the eastern Puna. It is only at the western margin that they become sufficiently extensive to be noticeable in the landscape. Thus, in the vicinity of Potosí, "the extensive intrusions of andesite into the Silurian schists have made the Sierra de Potosí the mighty, resistant, mountain mass which looms above its surroundings."[17]

The gentle folding of the Puna block in the first orogenic phase and the subsequent degradation are responsible for the main lines of the surface in the eastern Puna. These have been only modified (in no large area quite erased) and the area is therefore still morphologically a part of the Puna differentiated simply by the dissection that later set in.

The effects of the second period of diastrophism can be recognized in the eastern Puna only by the dislocation of the older Puna Fill. These dislocations are morphologically of little importance, the dislocated beds being covered by others that have remained in undisturbed horizontal position. The vertical movement of the second phase, however, became very important in the morphological development of the eastern Puna. The general uplift of the Puna block at this time resulted in the rapid growth of erosion valleys, on which terraces indicate that the movement was in several stages.

The forms due to present dissection.—Before the commencement of the second orogenic movement the eastern Puna was without doubt an undrained area with the characteristic forms of aridity at high levels. The uplift alone did not introduce the numerous streams. Only a simultaneous climatic change appears competent to have produced an extensive hydrographic net such as we now find. This process of recent dissection of course has been migrating slowly from east to west.

Two quite distinct morphogenetic processes are therefore taking place before our eyes. In the Puna proper and in isolated spots in

[17] Hoek and Steinmann, Erl. z. Routenk., *op. cit.*, p. 7.

the eastern Puna, basin drainage is filling in hollows and the process of leveling goes on. The eastern Puna has its western limit at the headwaters of streams that are incising and cutting back their valleys (pl. 6). As the process of erosion goes on, its area increases at the expense of the Puna proper.

The eastern Puna an association of climatically discrepant forms.—A partial discrepancy between climate and land forms characterizes the morphology of the eastern Puna, where we observed the remnants of the true Puna forms, originated under climatic conditions in which precipitation and evaporation were about balanced. About these relic forms are the deep erosion valleys, a genetically different morphologic element, produced under a moister climate, in which an excess of water had to find its outlet. These humid forms now prevail, having penetrated into structurally predetermined depressions.

This conquest of structural basins by erosion valleys that are growing rapidly in drainage area can be observed at various places in different stages. The road from La Quiaca to Tarija, for instance, passes through the depression of Tacsara (see map), a structurally closed valley. The northern part of it is still a fragment of the true Puna; two large lakes without outlet occupy it in part (pl. 4*a*). One of the affluents of the Pilcomayo has broken through in the south by headward erosion and a deep narrow gorge—la Quebrada Honda—now connects the once closed depression with the valley of the Rio San Juan del Oro. Its headwaters have begun to dissect the débris that fills the basin (pl. 4*b*). The watershed has been driven back hard against the lakes and it will be a question of only a short while until these are drained into the Pilcomayo.

The Pampa de Tacsara is a typical remnant of the true Puna just on the point of becoming dissected. As this process advances the Puna deposits are left only in the form of terrace remnants of soft sediments such as are to be seen along the road from Cotagaita to Tupiza, or even merely as isolated patches in protected nooks on the mountain sides, as they are found west of Otuyo along the trail from Sucre to Potosí.

The area shows throughout this intermingling of arid and humid land forms and herein lies its morphologic individuality. A boundary at the west, naturally, is hard to establish. The stream pattern decreases in density westward and thereby also the intensity of dissection. The more recent origin of the western drainage net, and in consequence its lesser development, provides a partial explanation of

this condition. This, however, is not simply an expression of age, since the decreasing precipitation eastward can hardly be explained adequately by a gradual extension westward of the rainier belt simply through the planing down of the Puna margin by erosion.

The belt of transition from Puna proper to dissected Puna is characterized moreover by a change in type of valley. The streams have their sources in gentle dales (pl. 5*a*), and incise themselves gradually to the point where they have deep erosional cañons, with incipient flood plains (pls. 5*b* and 7). The remnants of the old Puna surface, lying between the valleys, become progressively smaller eastward with increasing elaboration of the stream pattern.

Structural or erosional origin of valleys.—The manner, in detail, of the conquest of the eastern Puna by eastward flowing streams, especially by affluents of the Pilcomayo, is still unknown to us. There are, it is true, many erosional terraces in the valleys by means of which the problem might be solved, but the lack of sufficiently good maps makes it impossible to correlate the terrace remnants. However, the genetic interpretation of many of the valleys is still uncertain. In many cases there is doubt to what extent these are due to stream erosion and to what extent they are the result of orogenic forces. The first view of the Rio San Juan del Oro from the high Puna suggested a deep erosion valley like those which the affluents of the Pilcomayo have incised into the Puna block (pl. 7). The headwaters of the Rio San Juan, the Rio de la Quiaca (pl. 5*b*), the Rio de Yavi, the Rio de Lonte, and the Rio de la Quebrada Honda, are typical cañons eroded into the Puna Plain. A closer study of the Rio San Juan however brought the conviction that the Andean orogenic forces had contributed more to the formation of this valley than stream erosion, which in this case evidently resulted only in comparatively slight modifications of a structural depression.

The valley of the Rio San Juan del Oro follows in almost its entire extent the previously described Puca syncline that begins on Argentine territory and extends northward beyond Sucre. Cross-sections of the valley show as a rule the steeper dips on the western flank of the syncline (pl. 8*a*). In addition a continual change of the synclinal form can be observed, and the form of the valley changes with the form of the structure (fig. 6).

At the south, near Yavi, the greater part of the Puca sandstone lies under the younger Puna Fill, which there constitutes the surface of the Puna Plain. Only the highest parts of the red sandstone rise

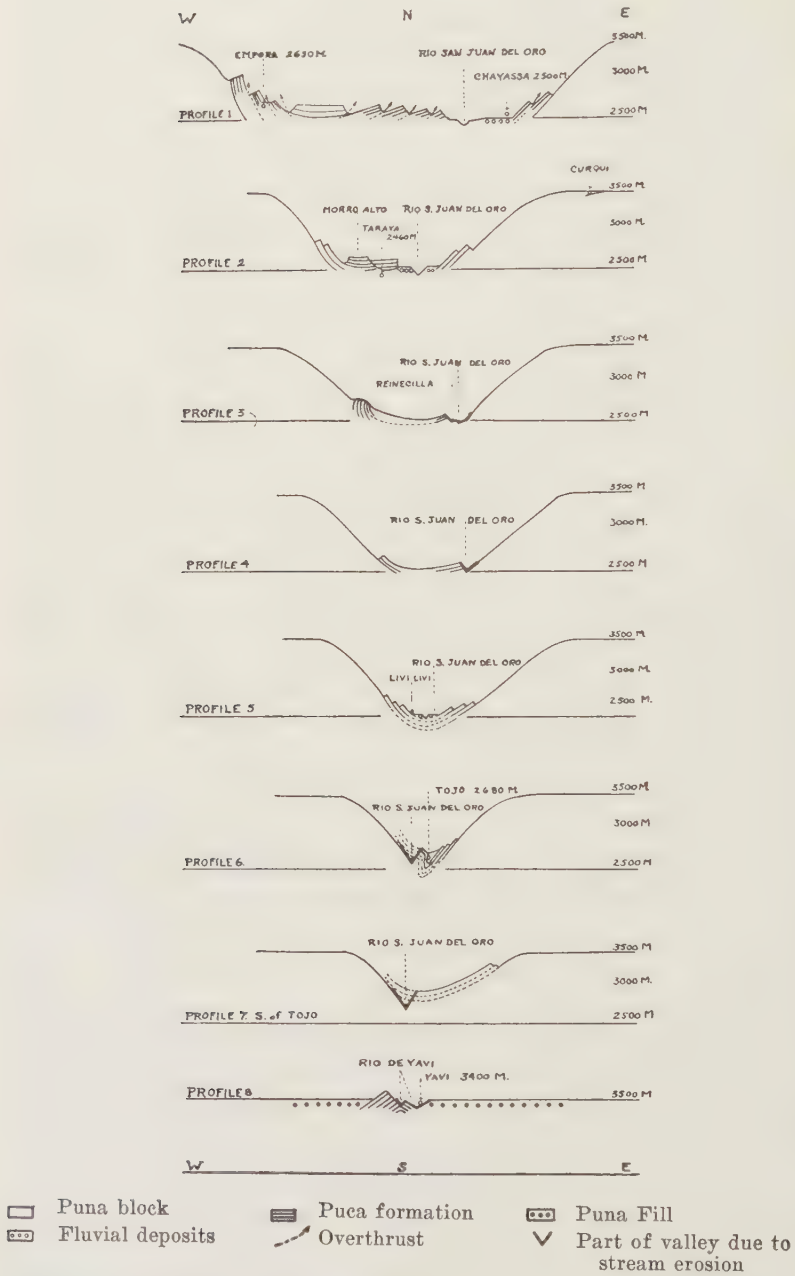


Fig. 6. Cross-sections through the valley of the Rio San Juan del Oro.

above the plain in the form of hogbacks, sloping toward the west (fig. 6, profile 8). The Yavi River, an affluent of the Rio San Juan, flows north along the scarp base of the hogback.

The hydrography is interesting, especially near Yavi itself. The river, upon which the village is situated, has incised itself about 120 m. below the surface of the plain of accumulation and exposed thus the Puca rocks that lay buried beneath the Pleistocene sediments. It was so superimposed on the sandstone as to cut through it twice. Thus is explained the remarkable fact that the stream crosses the sandstone dike twice, instead of following the shorter route.[18]

The epigene origin of the valley is evident here. There was no original relation of the valley to the Puca formation; this was developed only as the stream exposed these beds.

The situation is different to the north where the real Rio San Juan begins and here the relation between river and syncline is very close (fig. 6). For long stretches the stream is bottomed on the sandstone syncline. The bottom of the syncline has a gentle slope toward the north with varying dip, which is therefore not identical with the gradient of the river, the latter aggrading on the flatter portions of the syncline, trenching where the dip is steeper. For considerable distances, especially near Livilivi (fig. 6, profile 5) and from Escapana northward (fig. 6, profiles 1 and 2) the river flows directly in the syncline, which it accepts as its valley without modification. Remainders of fluvial terraces indicate that the river has in part filled the syncline with its deposits. These deposits are auriferous and it is for this reason that the river bears its name.

A résumé of the evidence as to the origin of the Rio San Juan valley gives the following results: At first view the valley appears so similar to those of the Pilcomayo south of Sucre, the Rio de Mataca (pl. 12*a*), and other normal valleys that its origin may be thought due to stream erosion. A knowledge of the structure, however, forces far-going revision of this concept. The valley coincides in part absolutely with the syncline of the Puca sandstone folded during the Tertiary movements. There are parts of the valley in which the structural topographic form is apparently entirely unmodified. Where the stream has cut well into the Puna block (Paleozoic) it has still formed only a small part of its valley. The valley floor is about 1000 meters below the level of the Puna plain and of this depression not more than 150 at a maximum can anywhere be attributed to erosion by the San Juan River (fig. 6, profiles 3, 4, 5, and 6).

[18] Hoek and Steinmann, Erl. z. Routenk., *op. cit.*

Only the fact that a part of the Puca sandstone has been preserved in the bottom of this syncline has given us the evidence of the structural origin and form of the San Juan Valley. Without this fortuitous condition it would be impossible to distinguish between the part played by stream erosion and the rôle of orogenic forces. This fact gives critical importance to the geomorphology of the San Juan Valley and raises the question as to the extent to which orogenic forces may have been involved in the formation of other valleys apparently formed simply by the dissection of the eastern Puna block.

The deeply sunk or incised valleys give to the eastern Puna its distinctive morphologic character and distinguish it from the Puna proper. These valleys are not only very conspicuous in the appearance of the landscape but they are of fundamental significance to human affairs in the area.

Glaciation.—Traces of glaciation are to be found only in isolated places. Glaciers were developed locally but had little significance in the general landscape. Glacial forms, such as may be seen in the Cordillera de Santa Victoria, Sierra de Camacho, Sierra de Liqui, and the Cordillera de Potosí, are excellently preserved, and although of secondary importance in a chorologic study, each of the areas mentioned would provide an interesting field for glacial investigation.

Hydrography

The drainage of the eastern Puna is, almost without exception, toward the Pilcomayo. Only occasionally, as in the case of the Rio San Juan del Oro and the Rio de Cinti, is a relation between structure and drainage evident. The exact course of most of the streams of the eastern Puna is not even known and hence little can be said regarding the control of the drainage.

The very porous débris on the Puna acts effectively as an absorbent of rainfall which sinks freely to the more impermeable Paleozoic beds. The latter form therefore a spring horizon of major economic importance. Especially near the heads of the valleys this horizon of springs and seeps provides the basis for small agricultural oases. The regimen of the streams is slightly affected by the presence of such springs.

Only the larger rivers of the eastern Puna are permanent. The slight significance of snow and springs and the strong seasonal rhythm of rain entrain extreme variations in flow. The larger the drainage basin the more regular the seasonal range; the small streams simply rise briefly during each rain, but may be dry a few days later.

Lakes in the eastern Puna are principally small glacial depressions, such as those in the Cordillera de Potosí. The Lagunas de Patancas are exceptional remnants of the undrained depressions common in the normal Puna. They are however doomed to disappear very shortly through dissection.

Climate

Climate of Puna Plain and Puna Valley.—As striking as the contrast between the extensive plains of the high Puna and the deeply incised valleys is the climatic contrast between the two areas. They have only one climatic feature in common, the seasonal distribution of the rainfall, the main rainy period being in summer. The

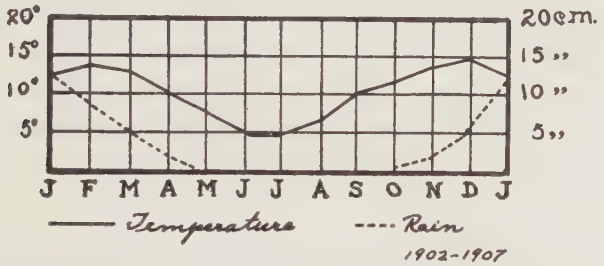


Fig. 7. Climate of La Quiaca, southeast Puna.

area lies in the tropics and has therefore the rainfall régime of its latitude. The eastern Puna has a pronounced dry season from April to November and a single rainy season, usually from December to March. The rainy period increases in length from south to north and the rains become more copious. There are no meteorologic observations from which a quantitative statement of this increase could be made. The best proof of it is found in the fact that the area in which agriculture is possible without irrigation becomes wider, that is, extends more and more to the west with decrease of latitude (fig. 10). In the latitude of Sucre, between Padilla and Potosí agriculture does not depend on irrigation; two degrees farther south cultivation is possible, at similar elevations, only by means of irrigation. In Sucre (2850 m.), the average annual rainfall is 700 mm., with a range from 519 mm. in 1896 to 806 mm. in 1887. The annual mean of La Quiaca (3460 m.), 340 km. south of Sucre and but little farther west, was 367 mm. (mean of 1902–1907) (fig. 7).[19]

[19] Davis, G. G., Clima de la Republica Argentina (1910).

Humidity and temperature on the plateau.—During the rainy season, the sky is generally overcast, especially in the afternoon, and brisk thunderstorms are common. The humidity of the air at this time is similar to that which prevails in northwestern Europe (fig. 8). As the sun moves north the skies over the Puna are cleared of clouds. In the months of May, June, and July even feeble showers are an unusual occurrence. The relative humidity at this season may sink to less than ten per cent; desert-like dryness may prevail, with discomfort to the traveler, arising from parched and chapped skin and irritation of the mucous membranes of nose and eyes. The physiologic effects of this winter aridity are heightened by the very intense insolation, the actual hours of sunshine being frequently equal to the

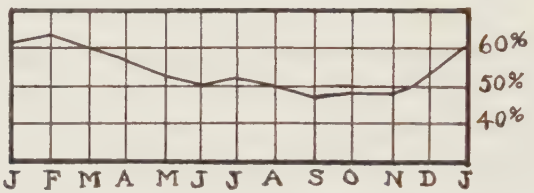


Fig. 8. Average relative humidity of La Quiaca.

possible hours of sunshine. In the cold season, when the temperature of the air on the Puna often drops below freezing and the nights especially may be cold (absolute minimum at La Quiaca —16.1° C) everyone gets into the sunshine as much as possible. Only in the sun can one be comfortable in winter, the contrast being always distinctly unpleasant when one passes from sun to shade, or if when riding, one has the same side of the body turned away from the sun for a period. In summer the days are for the most part comfortable on account of the blanketing effect of the clouds. Shade is welcome at that season. When the people are obliged to expose themselves to the sun in summer they protect themselves by enormously broad-brimmed hats that shade the entire body from the high sun.[20]

Comfort and discomfort on the Puna.—The dryness of the air, combined with the high insolation and the increased evaporation, partly in consequence of the low atmospheric pressure, results in physiologically agreeable effects. Perspiration is free and evaporates

[20] The traveler, unaccustomed to the intensive insolation on the Puna and exposed all day to the penetrating rays, is usually subject to excessive sunburn and blistering, protective formation of pigment being usually inadequate. Even after having become well-seasoned to the sun in the Chaco, the more brilliant irradiation on the Puna found my skin insufficiently tanned to escape blistering.

rapidly, giving reduced sensible temperatures and an agreeable sensation of refreshment accompanied by a distinct increase in energy.

At night the sky is usually clear and radiation is great. The diurnal range of temperature is therefore very high and may amount to 35° C in the course of a few hours.

Low temperatures are often made especially disagreeable by high winds. These winds develop usually in the afternoon, following strong convectional disturbance of the air through insolation. At night they die down; on very clear nights the air is ordinarily calm. The velocity of wind on the Puna is often very high but its effective force is sensibly diminished by elevation, perhaps by a third at an altitude of 3500 meters. During the dry season the wind brings discomfort blowing about fine particles from the sparsely covered surface. Dust storms are especially irritating to the eyes.

To the climatic factors that have direct physiologic influence should be added the psychological effects, visual impressions determined by atmospheric conditions. The brilliant light and the monotonous gray landscape oppress the mind after a time. When, after a march of days over this dun Puna, one comes to a lake on the plateau and the cries of gulls and the familiar smells of the strand evoke suddenly memories of the northern seas, the visitor from overseas experiences briefly a more buoyant mood than he commands on the great upland plain.

The lowland dweller who comes to the Puna experiences certain effects of the high elevation. At an altitude of 3500 meters, or thereabout, the lack of oxygen becomes sensible though not insupportable. At first the body is sensitive to slight exertion, resulting in shortness of breath, rapid pulse, sleeplessness, and headache. Stimulants have increased effect, and every excitation of the mind is felt more strongly and for a longer time than in the accustomed lowlands. All these phenomena however are temporary difficulties of acclimatization for one in good health. Only in the higher Puna mountains does the real mountain sickness (Puna or Soroche of the natives) develop.[21]

[21] There is still some uncertainty about the combination of conditions that causes mountain sickness. It does not appear to result simply from lack of oxygen and unequalized pressure, since its appearance is not a definite function of elevation. On the gentle slopes of the Puna highlands the sickness does not appear to be so violent as at equal elevations in other parts of the Cordillera. In the mining region of the Sierra Famatina, in the Argentine, most of my party, including myself, experienced violent illness with vomiting, acute headache, and nosebleed, at 4500 m., whereas in the normal Puna ranges at even higher elevations there was only minor discomfort. The dwellers of the Puna believe that the mountain sickness is especially *brava* in some places.

The climate of the Puna during the summer is quite agreeable for a North European. Winter weather, with the prevailing lack of fuel, causes one to bask in the sun at every opportunity, with some irritation to the nervous system resulting for the newcomer. But in general the Puna is free from ill health that is conditioned by climate.

Climatic change.—Climatic change during geologic time is indicated by the surface features, in particular there appear to have been greater cold and humidity in the late Tertiary and a depression of the snow line in Pleistocene. There is a suggestion that aridity has increased in more recent periods. The formerly cultivated terraces about the ruins of Palqui, near the Rio San Juan del Oro, are otherwise not easily explained. They are situated in an area where there is no known source of water for irrigation, yet where agriculture is now impossible without irrigation.

The most extreme climate is in the Puna ranges, which in part exceed considerably the 4000 meter level. Here precipitation may fall even in summer in the form of snow (pl. 3*b*), which however is soon melted. None of these mountains extend above the permanent snow line. During the Ice Age glaciers were formed in their higher parts but even then the lower limit of permanent snow lay above 4000 meters.

Valley climate.—The valleys and the structural basin of Tarija have a distinctive climate. The bottom of these depressions is between two and three thousand meters. They are therefore "islands of warmth," of especial significance in the economic life of the larger area. The conditions of precipitation are similar to those of the Puna plain and result in general in fairly well-marked aridity. In detail we know very little about the wind systems of the valleys, their direction being determined in general by the course of the valley. The great differences of temperature that often exist between the high Puna and the deep valleys give rise to strong valley winds. In the winter of 1924 the floor of the San Juan Valley was very comfortably warm during the day and early part of the night. However, after midnight, when the adjacent Puna upland had cooled far below freezing, this cold highland air poured regularly and steadily into the valley, and an icy wind blew down the valley until some time after sunrise. In numerous valley localities malaria is endemic, as for instance in the region of Camataquí on the Rio San Juan. In the absence of meteorologic observations of any length further inferences regarding climatic conditions must be drawn from the vegetation, concerning which more is to be said later.

Plant Life[22] in the Landscape

With the peculiar climate of the Puna is associated a characteristic cover of vegetation (fig. 9). We may leave open the evaluation of the relative importance of the several climatic factors; adaptation to

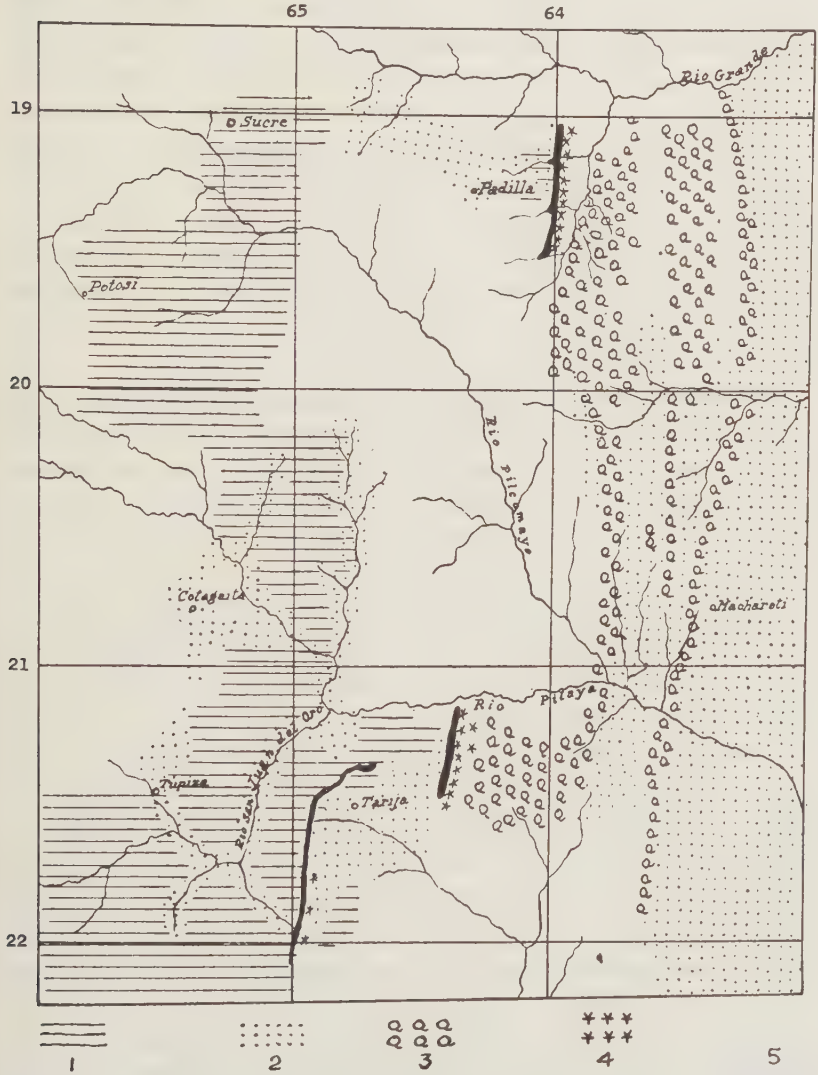


Fig. 9. Vegetation. 1, Dwarf scrub steppe of the Puna; 2, Monte: tree, scrub, and steppe; 3, deciduous mesophyte mountain forests; 4, coniferous forests; 5, Alpine formation: queñoa forests and meadows.

aridity is, however, especially conspicuous, and the effects of strong wind are noticeable in the twisted and gnarled forms of shrubs and small trees.

[22] Herzog, Th., Pflanzenwelt d. bol. Anden, Vegetation d. Erde, vol. 15 (1923).

The Puna contains several plant formations in the distribution of which elevation and humidity are notable determining factors.

Tola heath.—The most typical formation of the Puna, extending from the undrained areas of the west far into the dissected belt, is the *Tola* heath (pl. 3*b*). The native term Tola is a general expression for a group, primarily compositae, which form with their low, woody growths an extensive scrub steppe. The Tola is highly aromatic, the odor of the burning brush being especially distinctive. Since it provides the chief fuel for the highland dwellers their houses and furnishings are well impregnated with its smell. In fact one comes to associate the Tola odor directly with the Puna landscape. Among the Tola are interspersed the pillows of Llareta, masses of various species characterized by pillow form, highly resinous character, and often by a peaty transformation of their central parts. The Llareta is also employed as fuel.

Grass land.—Tough bunch grasses form an important element in the vegetation, especially the hard Puna grass, with its spear-like points (pl. 4*a*). Succulent grass also appears after a longer rainy period. It shoots up all over the Puna, inconsiderable in size, but an important fodder for the llamas.

Monte.—Where the high plains lie at elevations as low as 3000 to 3200 meters, the *Monte* reaches the upland. The Monte is a thorny brush of Quebracho, Chañar, Churqui, and other scrub trees and bushes which also form the Argentine Monte and the Chaco. The Monte that has established itself on the wind-swept heights of the Puna, however, is different in aspect from that of the low plains. The height scarcely exceeds a meter (pl. 3*a*) and the tops are strikingly sheared by the wind. Only where a creek bottom provides shelter and more water does the Monte occasionally exhibit its typical height of three to four meters.

Cardonales.—Columnar Cactaceae extend to an elevation of 3600 meters. They are found on the Puna proper only as isolated individuals, seeming to prefer the slopes of valleys. Otherwise their distribution is apparently without regularity. Where they occur in numbers they form the striking *Cardonales* (pls. 9*a* and 11*a*). In such cactus thickets they attain a height of several meters. Their singularly veined stalks are worked into boards, sills, and benches. The cardonales[23] are not a characteristic formation of the Puna proper but are a link with the vegetation of the valleys.

[23] Fries, R. E., Z. Kenntnis d. alp. Flora im n. Argent., *in* Nova acta regiae soc. sc. upsalensis, Ser. 6, vol. 1, no. 1.

Alpine vegetation.—The limit between Puna and valley vegetation is not expressed simply by elevation. In the arid valleys the typical Puna vegetation descends to 3000 meters, whereas on the eastern border of the Puna the plants characteristic of the higher valley slopes (alpine formation)[24] are found at 3400 meters. The eastern slopes of the Puna ranges receive much moisture from ascending air currents, as illustrated especially by the meridional mountains lying immediately west of Tarija (1900 m.) with summits between four and five thousand meters. Again, far to the north, a similar belt lies west of the Rio Acero. On such slopes the less xerophile alpine formation lies between the vegetation of the valleys proper and that of the Puna upland at altitudes between 2400 and 3400 meters, indicating the maximum of precipitation at such elevations.

On these high, moist slopes thickets of *queñoa,* one of the Rosaceae, appear, widely distributed as far south as the Sierra de Córdoba. Under most favorable circumstances it grows to a height of six meters. Its leaves are deep green and the rich brown bark peels off freely, whence it is known as *tabaquillo.* Normal alpine meadows are also developed at these altitudes on the slopes. The Valley of Camacho, south of Tarija, with its pleasant grazing grounds, forms in summer an especially agreeable contrast to the sterile Puna.

West of the eastern margin this alpine zone is soon lost. Descending for instance into the valley of the Rio San Juan, the transition from the xerophile Puna formation to the similarly xerophile vegetation of the valleys takes place without any intermediate zone of more mesophytic characters.

Vegetation of the dry valleys.—The vegetation of the arid valleys extends to a maximum of 3000 meters at the west. Where the alpine formation is introduced it is limited to elevations below 2600 or even below 2400 meters. Not only the dry climate but also the high porosity of the young detrital materials of the partially filled valleys and the structural basin of Tarija, help to explain the distribution of the valley vegetation.

In the valleys a shrub and park steppe is developed, such as characterizes the Gran Chaco. We have already noted stunted outposts of it on the eastern edges of the Puna. The floristic composition of this formation, the Monte, changes from place to place; the churqui, with vesicular fruits, being of greater range, especially in altitude, than

[24] Fiebrig, K., Beitrag z. Pflanzengeog. Boliviens, Englers Bot. Jahrb., vol. 45, no. 1.

the algarobo. The stand is always sparse and the trees are interspersed in many places with columnar Cactaceae, giving rise to cardonales. Along the stream margins the *molle* or pepper tree abounds, its great branches of deep green foliage constituting the finest adornment of the landscape. Where dissection is advanced and the original surface of the Puna is destroyed by erosion, this formation mantles the slopes even to the point of invading a few advantageous spots on the Puna.

Animal Life in the Puna Landscape

The sparseness of the vegetation is reflected in the animal world, which is nevertheless here and there an effective component of the landscape. The larger animals are seldom to be seen. Excessive hunting has driven the vicuñas into the most remote mountains and the puma also has become rare. Carrion birds, including the great condor, may be seen in the grazing areas and along the pack trails. At the lakes of Patancas there are always gathered swarms of aquatic birds. Wheeling gulls, groups of sedate pink flamingoes, and knots of black divers and ducks help to make up the scene.

On the high plains burrowing animals are especially numerous, vizcachas, small armadillos, and chinchillas, valued for their fur. After the first copious rains, when the Tola comes into flower, insects enliven the heath. On the formerly silent heights the chirping of crickets and other noises of the insect world become so strident and shrill as to weary the ear of the traveler.

The Settlements of the Eastern Puna

Lack of quantitative data.—Less adequately even than land forms are the cultural conditions of this area represented on existing maps. The local importance that even the smallest settlement has in a sparsely settled region tends to its exaggerated representation on more general maps. Thus on Huot's map a tumble-down hut containing at the time of my visit an old woman and two children, Palos Blancos, in the forested mountains of the east, is shown as equal in importance to the busy town of Vitiche, whereof the houses extend for several kilometers. In the more densely populated regions very numerous settlements of small size are not represented at all. Since there exist no statistical accounts covering the rural districts, and little geodetic determination, a substantial graphic representation of

distribution of habitations is at present unattainable. Not even the difference in density of population, which is, of course, much greater in the irrigated valleys than on the arid Puna, can be expressed numerically. There remains the possibility of personal observations on a sufficient number of settlements to establish typical forms. Such a rough classification of settlement is attempted in the following pages.

A belated Inca frontier.—The history of the settlement of the eastern Puna is lost in its beginnings because of the lack of a written record. There is evidence that the highland culture never extended east beyond the limits of the Puna. On the contrary, the Chiriguanos, of the east Bolivian front ranges, invaded the highlands from time to time, attracted by the possibilities of plunder. The Incas had to fortify this frontier for protection rather than as a base for expansion.

Sarmiento de Gamboa reports frontier fortifications which the Inca Tupac Yapanqui erected in the vicinity of Pocona, east of Cochabamba, against the Chiriguanos and which his son, the Inca Huayna Ccapac (1464–1525), found it necessary to repair.[25] Nordenskjöld considers that these fortifications are preserved in the ruins of the fortress Incallacta (Quichua for Inca village), discovered by him at a distance of little more than twenty kilometers from Pocona, there being no other notable ruins in the vicinity.[26] Somewhat later the Chiriguanos entered again the territory of Charcas,

> coming forth from their dense forests, they attacked the fortress of Cuzco-tuyo, where the Inca had a large frontier garrison to defend the country against them. Their assault being sudden they entered the fortress, massacred the garrison, and committed great havoc, robberies, and murders among the surrounding inhabitants. The news reached Huayna Ccapac at Quito. He sent a captain named Yasca to Cuzco to collect troops, and with them to march against the Chirihuanas. . . . Having collected his troops he left Cuzco for Charcas. On the road he enlisted many men of the Collao. With these he came up with the Chirihuanas and made cruel war upon them. The captain Yasca rebuilt the fortress and, placing in it the necessary garrison, he returned to Cuzco.[27]

Not only was the defense of the eastern border troublesome to the Incas, but their dominion over the Puna dwellers south of the Rio Grande was established late and was never fully effective. In particular the brave Chichas Indians of the south in the region of the

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[25] Sarmiento de Gamboa, P., cosmographer of Peru: Segunda parte de la historia general llamada indica (1572). First published in Abh. k. Ges. Wiss. Göttingen, phil.-hist. Kl. (1906). Here cited from Hakluyt Society edition, translated by Sir Clements Markham (1907).

[26] Nordenskjöld, E. v., Incallacta, in Ymer, vol. 25 (1915), no. 2.

[27] Sarmiento de Gamboa, *op. cit.*, chap. 61.

present Tarija were defeated but never really subdued. The northern part of the eastern Puna, inhabited by the Charcas Indians, was conquered by Tupac Amaru and Apu Paucar Usnu, sons of the Pachacuti Inca Yupanqui (1294–1397?), who had defeated the combined armies of the Chichas and Charcas.[28] It remained for Huayna Ccapac, who died two years before the coming of Pizarro, to establish *mitimaes,* colonists of Quichua speech, in the valley of Cochabamba and thus to make a belated attempt to incorporate part of the Puna margin into the Inca empire.[29]

Though the political extension of the Incas took place almost at the time when their realm began to fall before the attacks of the Spaniards, nevertheless Quichua speech, the speech of the Incas, together with Spanish, is the language of the area today. A few local names record the former existence of the Aimara language, once extending south at least as far as Talina.[30] There appear to be no remnants of the other languages formerly spoken by inhabitants of the area.[31] Quichua names are restricted to the Puna, Chiriguano to the forest lands of the east. The limits of landscape and language correspond very closely. Some decades have passed since the eastern limit of the Quichua language coincided absolutely with the eastern margin of the Puna. More recently the highland Indians, especially the Cochabambinos, are beginning to penetrate into the forest as traders and to settle down in small communities.

Pre-Spanish ruins and the changes in settlement under colonial administration.—The aspect of the rural settlements appears to have suffered no major modification either by Inca or Spanish conquest. With them became associated the urban settlements of the Spanish colonial period, but even here it appears that the foundations go back considerably farther. Only in the eastern margins of the high Puna did the highland Indians abandon a number of places when the Spaniards came to rule. Here a fundamental change in living conditions was introduced. The Spaniards supplied to this border zone protection against raids from the forest Indians and against the unsubdued Chichas living south of the Pilcomayo. As law and order were introduced it was no longer necessary to confine settlement to protected sites.

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[28] *Ibid.,* chap. 41. [29] *Ibid.,* chap. 59.

[30] Uhle, M., "Reisen in Bolivien," Verhdl. Ges. Erdk. Berlin, vol. 21, p. 328 (1894). He mentions a strangely formed rock near Talina, called Skunkani, and the name Membrilluni in the valley of Cotagaita as Aimaraic forms.

[31] Ynca Garcilasso de la Vega, "Royal Commentaries of the Yncas," etc. Quoted from translation by Clements Markham, book 4, chap. 18, p. 335.

The number of abandoned settlements of the time of the Incas—designated *pueblos viejos, pueblos de los infieles,* or *antigales* by the natives—appears to be considerable, but little is known concerning them. The ruins visited in the valley of the Rio San Juan del Oro are all so placed that the desire for protection is apparent (*Schutzlage*). Settlements at no considerable height above the valley floor, but so situated as to be difficult of access, are to be found near Escapana on a river terrace about thirty meters above stream level, and also near Taraya on the Morro Alto, a detached sandstone block which is somewhat troublesome to climb. As only the valley floor itself can be irrigated and cultivated, and the settlements are not placed so as to escape floods or to have climatic protection, only the fear of invasion is likely to have obliged them to live on these heights, from which they had to climb down to till their fields and perform their occupations. After the Spanish conquest they came down from their fortresses and spread out along the lower parts of the slopes. Here we find their descendants living to this day. The ruins of Escapana and Taraya are sadly decayed.[32]

On the highlands of the eastern Puna are situated several ruins of pre-Colonial time. One of them, the mountain fortress of Condor Huasi (Quichua for Condor house) has previously been described by myself.[33] It is situated at an elevation of about 4000 meters on the side of a normal Puna mountain. Eastward it is protected by a cliff of (Palaeozoic) sandstone, to the west by a long defensive wall supplied with numerous loopholes. The buildings are well preserved except for the roofs (pl. 9*b*). The fort is very isolated and no traces of former culture of any sort are to be seen in its vicinity. Only on the mountain heights there are ancient *pircas,* stone corrals that served as traps for *vicuñas.* It appears that the settlement served only military purposes and formed part of a series of frontier forts which Cieza de Leon mentions.[34]

Still more impressive are the remains of the old settlement of Palqui (pl. 9*a*). This ruin is situated at about 3200 meters, also on

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[32] I heard of still other abandoned settlements of similar position in this valley but lacked time to visit them.

[33] Petermanns Mitt., nos. 9, 10 (1924).

[34] Second part of the Chronicle of Peru, translated by Clements Markham (London, 1883), p. 69, "the Chiriguanas . . . . whose lands are on the slopes eastward of the Andes, are wild and very war-like. To guard against this evil, there were garrisons in many parts . . . . whose duty it was to hold and defend the forts, called "Pucaras," if it should be necessary. Provisions were supplied to the soldiers of the maize and other food, which the neighbouring district paid as a tribute."

the Puna plain, east of the Rio San Juan del Oro and not far south of Condor Huasi. It lies on a small erosion remnant between two great cañons. Many portions of the walls are still standing, and indicate buildings of considerable size and number. Between the walls run well preserved paved roads. The whole site is now occupied by a large cactus forest, the trunks in part growing out of the walls of the ruin. On the very steep slopes just below the ruins are numerous terraces which were once cultivated. There appears to be no possibility of former irrigation unless water was brought up from the meager creek far down the valley.

In a similar position somewhat farther south is the ruin of Ñoquera. I had information about this place from the natives but did not have occasion to visit it.

Of still another type is the group of pre-Spanish ruins in the valley of Camacho south of Tarija. The striking contrast between the Puna landscape of Patancas in the west and the deep valley to the east has been mentioned. The green valley was an attraction to the highland Indians and they wrested it from the Chichas. The two ruins of which I know are situated quite near the foot of the Puna ranges against the eastern slope and suggest a certain lack of assurance on the part of the conquerors, who appear to have remained in a position where they could most readily get support from their countrymen on the heights or retire in case of an emergency.[35]

The Antigal de Camacho, the great abandoned settlement a little to the west of Aliso, is situated where the narrow and steep trail comes down from the Puna by way of the Cuesta del Inca to the Valley of Camacho. Remnants of numerous house walls are still standing and a broad, dike-like road runs between them (pl. 8*b*). The settlement is situated on the alluvial fan of a creek that crosses through the ruin. All the stone for construction appears to have been secured from the creek bed, none of the material being cut.

A certain number of border settlements of the old Inca empire, that were apparently made more for protection against foreign enemies than for their economic attractiveness, were thus abandoned with the beginning of the Spanish period. The ones described are only some of the instances, the total number being possibly consider-

[35] E. v. Rosen, Arch. res. on the frontier of Argent. and Bolivia, 1901–1902, Smithsonian Rep., p. 579 (1904), found another ruin not much farther north near Tolomosa but did not describe its exact location. Nordenskjöld, E., Travels on the Boundaries of Bolivia and Argentine, *in* Geog. Jour., vol. 21, p. 52 (1903), characterizes these ruins as "probably purely Inca in origin."

ably greater. To determine this however would require an intensive exploration of the entire frontier.

Recent growth and decay of settlements.—Most recently decay has overtaken Camacho, south of Tarija. In former days Camacho was a market town with a noted fair, the chief basis of its wealth. When the Argentine railroad from Jujuy reached the Bolivian border the fair was removed to La Quiaca and Villazón, the Argentine and Bolivian border towns situated at the crossing of the frontier by the Buenos Aires–La Paz railroad. A large number of substantial houses, now in ruins, still give evidence of the former flourishing state of Camacho. The other settlements of the eastern Puna have persisted from Inca days and have developed in the course of the centuries to their present state. Only a small number of colonial towns were added.

Cultural forms of Indian settlements.—The Indian settlements which the Spaniards found usually bear Quichua names. Where their meaning is still recognizable their names often reflect some characteristic feature of the landscape. Ichu pampa is the high plain where the hard Puna grass grows, commonly used as thatch. Taco taco is the place where there are many algarobos, Rumi rumi, that of many stones, Tiu mayu, the sandy river. Taco payo is the old algarobo tree and Condor Huasi the house of the condor.[36]

In the varied forms, sizes, and situations of the settlements purely Indian in origin certain repeating characteristics may be found. In the first place there is a fundamental difference between the settlements of the arid plateau of the south and those of the moister parts of the Puna and of the valleys.

Indian habitation in the arid Puna.—The most primitive settlements are those of the southern Puna (pl. 10*a*). They are widely scattered, small ranchos, the buildings consisting of dwelling, kitchen, and shed, each of minimum dimensions. Undressed field stones chinked with clay form the walls. The roofs of Puna grass rest on joists that have commonly been brought in from great distances. Sills and furniture are fashioned from the columnar cactus. Windows as a rule are wanting. Built out of the rocks of the landscape, small, and squat, these structures are most inconspicuous. The few square

[36] Other local names, of more recent origin, are the result of combining a Quichua and a Spanish word, such as Lorito caca, the parrot rock. Since the beginning of the past century, however, many of the old Quichua names have been sacrificed to commemorate Bolivian national heroes. Only in the mouths of the Indians does Sucre remain the old Chuquisaca; Millares, the Llanta Apacheta; and Sudañez, Tacopayo.

rods that are planted to potatoes and beans, conveniently near the house, do not call much more attention to the presence of a habitation. The flocks of sheep, goats, and llamas usually graze far away from the homes, especially in summer when they wander into the heights of the mountains.

Where water is more abundant, especially in the spring-fed dales at the heads of valleys, some hundreds of acres of irrigated land may be found (pl. 5*a*). At such sites a certain concentration of ranchos takes place, a clustering of small farms however rather than the development of a village structure. Such non-nucleated settlements are Sansana (pl. 5*a*) and Escayache, near La Quiaca, each having an extent of several square kilometers. In still other cases, as at Mojo, the scattered ranchos have developed a small community center, consisting of a modest church, the house of the cura, some very primitive stores, and the dwelling of one or more rural proprietors of a somewhat superior station.

There is still another type of settlement that is bound to these spring-fed dales. In the latter case only the fields are situated on the lower ground, the dwellings lying together on higher slopes, the people going in some cases a considerable distance every day between their fields and homes. In general the dale settlements are quite conspicuous, not on account of the buildings, for these are neutral like the other habitations of the upland, but on account of the vivid green of their amply watered fields.

Indian habitations on the humid Puna.—Farther to the north the aspect of settlement changes as agriculture becomes more independent of irrigation. The site of settlement is no longer closely controlled by the availability of water, and isolated ranchos are widely scattered over the surface of the plateau as well as in the moist basins. These isolated homesteads almost without exception evince the very low standards of living of the farming Indians who inhabit them. In construction they are in no wise different from those described above.

As there are very numerous scattered settlements in the north of our area there have also developed on the plateau villages and towns that are supported by the country population. On the road between Padilla and Sucre one finds about every forty kilometers a place of two thousand or more inhabitants. In plan these large towns, mostly consisting of full-blooded Indians, indicate their pre-Spanish origins. They have usually the apparently irregular ground-plan characteristic of the abandoned Inca places. The straight streets of the colonial

period are of limited development. The houses are higher and larger than in the rural districts, some even have two stories. Adobe is much used and the roofs are the common half-tiles of Spanish-American towns. Tarabuco, Yamparaez (pl. 12*b*), Puna, Otuyo, are types of these Indian towns of the Puna.

Valley settlements.—In the more arid south the contrast between the sparsely settled Puna and the more densely populated deep valleys is most striking. Entire valleys form one continuous settlement, rarely known by a single name however. Where the valley floor is broad the individual ranchos lie on the lower terrace in the midst of irrigated fields. In the narrow valleys, on the other hand, the houses are situated like small castles on salients of the valley sides (pl. 15*b*). The stream bed then forms the village street along which one may ride for hours between ranchos scattered along both sides of the valley.

The larger valley settlements have as a rule a well-defined nucleus (pl. 12*a*) of quite impressive appearance, with church, market-place, and numerous stores. Vitiche is an illustration in point. The construction of the dwellings is superior to that on the Puna; the houses are more spacious, with walls of dressed stone or adobe. Very common is the custom of covering the roofs with large slabs of schist daubed over with mud (pl. 10*a*).

The Spanish towns.—A class unto themselves are the towns of the Spanish period. Padilla may be regarded as a transition form, having the colonial quadratic ground plan but an architecture and population that are scarcely distinguishable from a full-fledged Indian town such as Tarabuco. The larger colonial cities, however, such as Sucre (29,000 inhabitants in 1919) and Tarija (13,000 inhabitants in 1919), have quite the character of the older Spanish foundations in the New World (pl. 13*a*) and many of the inhabitants are of European stock or of mixed blood. Sucre has developed from an important settlement of the Charcas Indians (Chuquisaca). In Spanish days it was known as La Plata. The city is the center of an important agricultural area embracing the humid Puna with its comparatively dense rural population. The stage of agriculture is the same today as it was in the days of the Incas. The same methods are employed and there does not appear to have been an extension of agricultural surface. These conditions are reflected in the slow growth of this, the dominant urban center, which had 20,000 inhabitants in 1807. In the southern, more arid part of the Puna no comparable center has developed. Only in the depression of Tarija the colonial city of the same name has been produced out of its immediate surroundings.

The most Spanish of all Bolivian towns, Potosí, officially "*la esclarecida y opulenta ciudad de Potosí,*" lies a short distance beyond the eastern Puna. At an altitude of 4000 meters, it is too cold for agriculture and it owes its importance to the rich ore bodies of the Cerro de Potosí, at the foot of which it lies (pl. 13*b*). These ores are related to igneous intrusions which are wanting in the eastern Puna in general. The phenomenal returns of old that were secured from this mining district have left more ample signs of past magnificence than any other city in America exhibits. No one can see Potosí without having respect for the energy of the conquistadores.

As a site for a city it would be hard to make a less promising choice than that of Potosí. The elevation is four thousand meters at the chief plaza. Neither tree nor brush grows anywhere about and there is neither timber nor fuel available locally. There is not sufficient agriculture in its hinterland to support an urban population. Glacial lakes to the east and northeast supply water in abundance. A limitless supply of building stone is provided by moraines that descend into the upper parts of the city. But the riches of the Cerro de Potosí in minerals were so great that in its most brilliant days, the time of Charles V, Potosí is said to have contained two hundred thousand inhabitants. Today there are about thirty thousand. Consequently there is a great number of dwellings and even of public structures in decay and almost no recent construction. Most of the houses are of the colonial period and style. Only in the suburbs, where Indians dwell, are the simple ranchos of the rural districts to be found. In the public buildings dressed and carved stones were employed lavishly. In numerous splendid churches and convents and in the mansions of grandees, embellished with coats of arms, the proud past is still preserved (pl. 14*a*). The former mint, in particular, is monumental. Its enormous beams were brought with prodigious effort from the far forests of the eastern ranges, trains of hundreds of Indians being employed on marches of months. Today there exists not even a road into these regions.

The rich Bolivian mining districts lie properly to the west of our region. A little mining is carried on in the young eruptive rocks occurring here and there in the eastern Puna. A few small mines producing galena are worked during favorable times. About them are temporary Indian settlements that fill up as the price of lead rises and disappear when the prices fall again.

Distinctive types of settlement are those of La Quiaca (pl. 11*b*) and Villazón. Fifteen years ago they were straggling villages, La Quiaca with a hundred inhabitants. The extension of the Argentine railroad to the frontier transformed these border settlements into important trade centers. The new La Quiaca was built at some distance from the old frontier post. It has now a branch of the Argentine national bank and several hotels. It has further attracted to it the *Manca fiesta,* the fair long held at Camacho. The completion of the La Paz–Buenos Aires railway, now impending, will enlarge the significance of these frontier towns.

Land Utilization

In the whole of the eastern Puna agriculture and stock-raising are dominant (fig. 10). With areal changes in natural conditions, agriculture takes on different forms from place to place.

Utilization of land in the Puna.—The plains and heights of the dry Puna are adapted only to stock-raising. In addition to llamas and burros, only sheep and goats can subsist on the meager pasturage of the plateau. Cattle do not find sufficiently succulent grass; hogs do not reproduce at these elevations. Little care is bestowed on the stock which roams about at will. The Indians do not even take the trouble to shear the animals at regular times. When wool is needed for domestic use or to raise money, as much is clipped as is needed. The flocks of sheep in particular are therefore in deplorable condition, and the quantity and quality of the wool produced is low.

Compared with the poor pasture land the area of the moister, cultivated dales is small. The estate of Señor Escalier, for instance, lying north of the Argentine border, comprises 175,000 hectares, including the usual amount of Puna plains, basin land, and deep valleys. Of this entire surface only 800 hectares are under cultivation and this proportion is considered as above the average.

In those basins which contain springs (*Quellmulden*) irrigation presents no problems. Small ditches carry the water along the slopes to nearby fields. The frequent frosts restrict the number of plants that can be cultivated, alfalfa, potatoes, barley, and beans forming the chief crops. The agricultural methods are the same as those of the Aimaras and Incas. All innovations are resisted. Even the iron plow is not in use, the soil still being scratched with the immemorial wooden plow (pl. 16*a*). Since the soil has been exploited

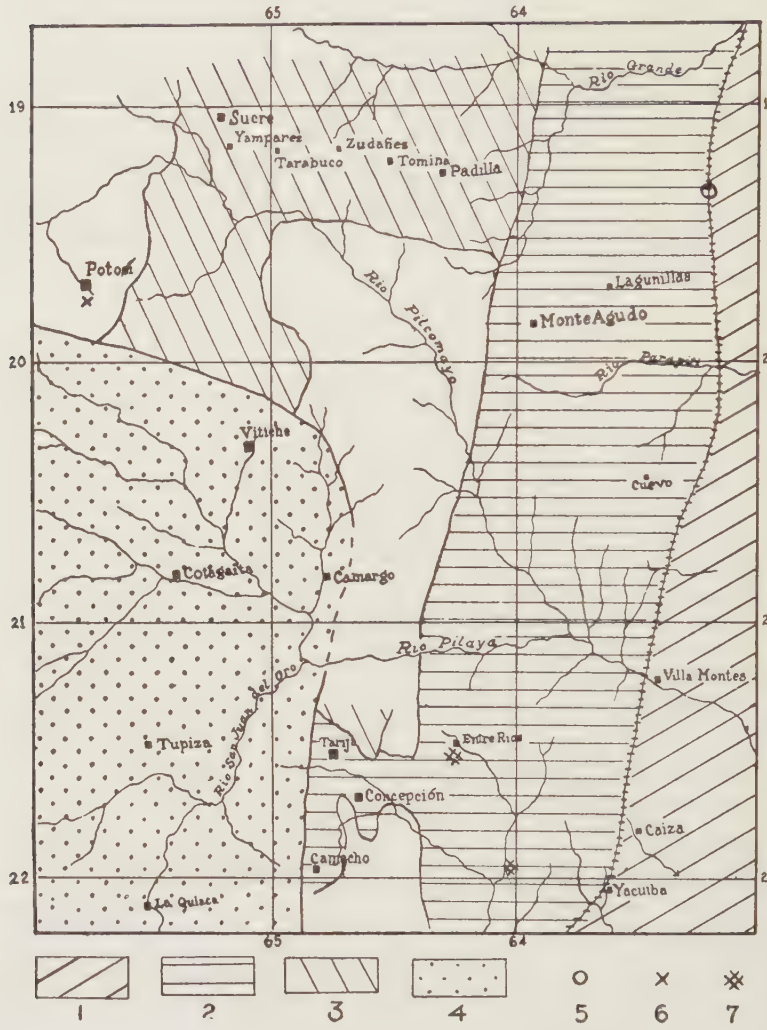

Fig. 10. Land utilization. 1. Cattle-raising prevails. Small unirrigated cornfields near settlements subject to drought. 2. Agriculture based on rainfall (mainly corn growing) combined with stock-farming, especially cattle and hogs; in the depression of Tarija also horses. 3. Agriculture based on rainfall to heights of 3800 m.; alfalfa, barley, and potatoes; at lower altitudes also corn and wheat; irrigation only for horticulture. The extensive fallow land forms poor pasturage for sheep and goats. 4. About two per cent of the area irrigated and cultivated. Alfalfa most important crop; horticulture, maize, wheat prevailing below 2600 m.; barley and potatoes at higher elevation. At about 3500 m. summer frost limits agriculture. The main part of the area consists of poor pasture land sparsely stocked with sheep (about 3 pr. ha.). 5. Productive oil wells of the Standard Oil Company of Bolivia. 6. Mining districts of the Puna proper. 7. Salt beds.

for many centuries its productivity is in many cases very low. A little animal manure is being used but commonly the land is fallowed, sometimes from three to twelve years. With abundant irrigation, however, crop follows crop without interruption.

Farther north where the rainfall becomes greater and agriculture is possible without irrigation, the character of the agriculture changes gradually. At first, one sees a few small fields on the slopes, the lower, irrigated fields still constituting, however, the main basis of agriculture (pl. 15*a*). In the latitude of Sucre extensive fields cover the heights of the Puna. Here the bottoms of the valleys hold only small gardens under irrigation.

Valley cultivation.—The Indians of the southern valleys carry on agriculture and horticulture, depending almost exclusively upon irrigation. Depth and narrowness of valleys commonly put a premium on small pieces of land situated within the valleys wherever the slope is not too steep and where water is available. The valley of the Rio San Juan del Oro is in part so narrow that there remains no other possibility but to cultivate the very river bed (pl. 15*b*). Immediately after the rainy season in May or June, when the level of the river falls strongly for several months and the water covers at last only a small fraction of the stream bed, grain is sown in the bed and harvested before the first summer flood comes, usually in November.

Economically the valleys form the most important and most fortunate parts of the eastern Puna. What the highland dweller lacks, the Indian of the valley enjoys. The number of cultivated plants is large in comparison to the upland. The mild climate enables two harvests of grain a year. The fields are covered with fertile mud at each irrigation. The water is first directed into small ditches so as to become loaded with sediment and thereafter distributed over the fields.

Corn, wheat, and alfalfa are the chief products. Olives, peaches, vines, pears, apples, and tomatoes grow luxuriantly in gardens; all of these are wanting on the Puna.

Colonos and comunarios.—For those Indians who are small landed proprietors, as for instance at Curqui, Sococha, and Yuruma, the produce of the land suffices for the satisfaction of their wants. Outside employment is however almost universal among the tenant Indians. Some are obliged to work throughout the year on the fields of the landlord as day laborers, at a wage from thirty to eighty centavos per day. The proprietor pays a part of the wages in cash, another part

is retained as rent, and the rest is taken out in merchandise which the proprietor dispenses at a profit. The *colonos,* or Indian workmen on an estate, form by tradition an inherent part of it, and the value of such an estate, or *finca,* depends in considerable part on the number of colonos that goes with it.

A distinctive type of property is found in the *comunidades,* small agrarian communities which go back to the time of the Incas when the Indians had no private property.[37] Since the government abolished this institution in 1882, they are called *excomunidades.* Practically, however, they persist, and the *Indios comunarios* cannot as yet dispose freely of their land rights.

The different types of ownership, however, have no influence on the cultural landscape. Form of settlement and agricultural methods are the same in a region where the land belongs to small proprietors and in one of large estates. The fields cultivated directly for the proprietor are never extensive. The administration of the larger estates is therefore complicated and the control difficult. Every colono has kept for him an individual account with detailed provision for his various services. The administrative personnel is therefore relatively numerous and the returns would be unsatisfactory if the system were not based upon as gross an exploitation of the Indian as that to which he in his turn subjects the land.

Migratory labor.—In general life is very difficult for the Puna dweller. As land prices are very high, ranging around 600 Bolivian pesos per hectar under irrigation, there is not the least possibility for him to acquire the smallest fraction of land through saving. What he earns is just sufficient to give him his bare life and, from time to time, to provide a spree. But when he comes in contact with better working conditions, that is, when a foreign company constructs a railroad in his neighborhood, he abandons his home without ado and goes on with the advancing railroad. The first consequence of the construction of a railroad is often, therefore, the depopulation of the countryside to the benefit of the mining districts, since these are the primary occasions of railroad construction.

The pastoral Puna Indians are strongly dependent on areas of different economic organization. They have to offer at most some

[37] Cunow, H., Soziale Verfassung des Incareiches, Stuttgart (1896). *idem,* Altperuanische Dorf u. Markgenossenschaften, in Ausland, pp. 820–825, 833–856, 872–878 (1890); McBride, G. M., Agrarian Communities of Highland Bolivia, Am. Geog. Soc. Res. Ser., no. 5 (1921); Pfannenschmidt, E., Boliviens Land u. Volkswirtschaft, *in* Ber. Land u. Forstwiss. i. Ausl., Auswärtiges Amt (Berlin), no. 24 (1916).

cloth, *bayetas,* with a little wool and some goat skins in exchange for other necessities. Their stock is usually insufficient to support them and they therefore hire out with burros or llamas, to carry supplies to the mines and to carry ore or metal to the railroad.

When the proprietor does not have employment for his tenants they are obliged to look for support elsewhere. Economic conditions such as those at Sansana then develop. The settlement is scattered over a small basin in which beans and potatoes are produced as staple food and alfalfa for the feeding of mules. The whole village is inhabited only by muleteers who seek work far in the interior of Bolivia, and return home at intervals to look after their fields and to recondition their animals.

A Static Feudalism

The exploitation of a poor country by an indolent population in a most primitive fashion maintains the population at the minimum level of subsistence. In addition the highland Indian must in general pay rent, for in most cases he does not own the land on which he subsists. For each head of stock he usually pays at a definite rate, commonly forty Bolivian centavos annually per sheep, and four pesos per donkey. Another arrangement is that the tenant works a certain period at a nominal wage on the fields of the proprietor, for example, a month during seed-time and again a month at the harvest. Also a fifth of his pack animals are impressed into the service of the landlord.

The economic situation of the freeholder is not so hopeless as that of the tenants of the large estates, many of which have remained in the hands of the same family since the first years of the Spanish conquest, employing for centuries the same methods of exploitation of the Indian. This feudal continuity explains the extreme dullness of the Indians. Whether lazy or active, working with old or with improved methods, the benefit was not theirs. They have had for generations a bare living and have always been in debt to their master, who could take what he wanted. But whether an original racial character or an acquisition of the colonial system, the indolence of the highland Indian is today a factor which makes modern developments of agriculture in the eastern Puna absolutely impossible.

The rural towns exist because in them the Indian sells that small excess of his produce which he puts aside in order to buy the most urgently needed goods. Direct foreign importation is primarily

through a small group of foreigners, mostly Germans, in Sucre. The retail trade is in the hands of natives and Turcos, Levantines of various sorts, who are to be found in the farthest reaches of the interior. The scale of this trade is such as one finds in the Jewish quarters of west Russian towns. Every room is a store, the proprietor squatting behind a small table which holds the entire stock worth often only a few dollars.

The towns of the eastern Puna do not enjoy a brisk trade; this becomes especially clear by contrast with the more westerly cities in the neighborhood of the mines. Potosí, for instance, is a town where commerce and traffic goes on all the day and continues late into the night. Again, on the railroad at La Quiaca and Villazón, the foreign elements and greater activity convey a different impression than do the quiet Puna towns.

Communication in the Eastern Puna

Lack of improvements.—Since the eastern Puna is divided into a number of economic units which are strongly interdependent, there exists a brisk interchange of products. One might therefore suppose that a road net and the means of communication would be well developed, but the contrary is true (fig. 11).

The rivers of the eastern Puna have only the negative importance of obstacles; railroads exist only in the extreme west. The railroad from the south extended, in 1925, to Tupiza. The railroad Uyuni–La Paz has a branch at Rio Mulato to Potosí; the prolongation of this line to Sucre, the constitutional capital of Bolivia, was not yet finished in 1925. The operating railroad lines are in general indifferently constructed. Thus the roadbed crosses many steep débris fans which slip after every heavy rain so that the lines are interrupted, sometimes for weeks. The traveler who chooses the route from Europe to La Paz via Buenos Aires may be disagreeably disappointed.

It is the same with the roads for wheeled traffic, now mostly called *caminos de auto*, automobile roads. There is one such road from La Quiaca to Tarija (pl. 4*a*) which crosses the Cordilleras de Santa Victoria and Camacho by means of passes at about 4000 meters. Wheeled traffic on this road is likely to be suspended for weeks in summer. When the river rises to the summer flood stage the town of Tarija is isolated from any communication with the rest of the world.

Another road runs from Potosí by way of Sucre to Cochabamba and crosses the Pilcomayo on a good bridge, one of the few in eastern Bolivia. This road was found, January, 1925, in such a state as the result of rains that we had difficulty in getting over it with our animals (pl. 18*a*).

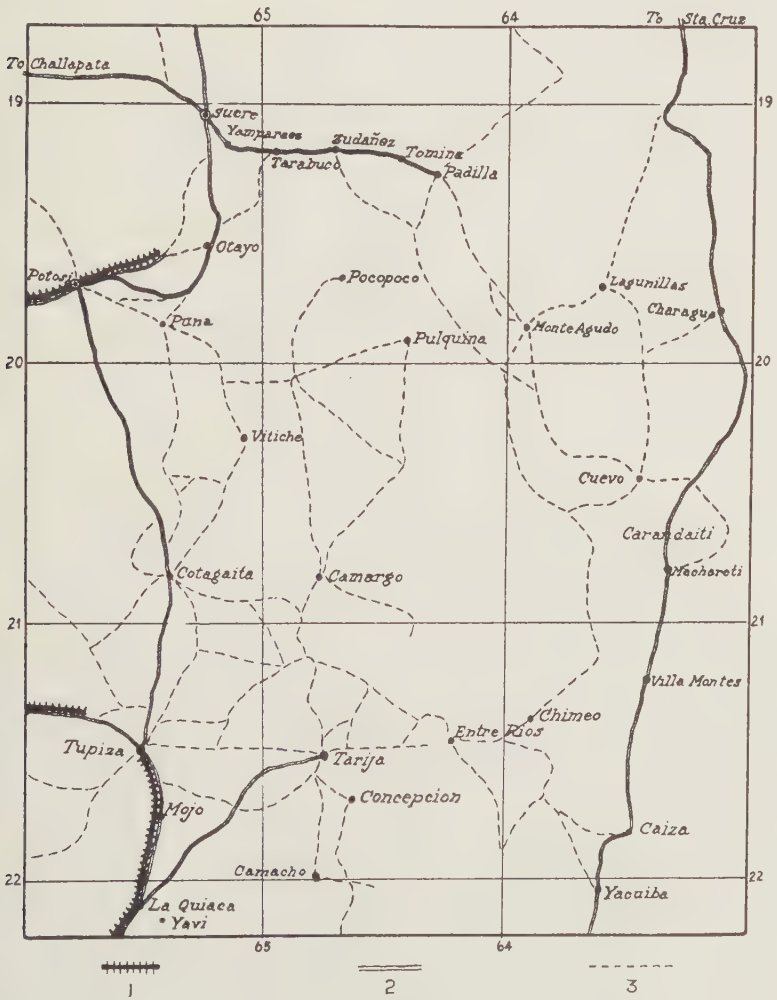

Fig. 11. Communications. 1. *Railroads* restricted to the Puna. The lines penetrating the eastern parts of this landscape are often interrupted during the rainy season. Passenger traffic, mineral transport to the coast, and importation of goods. 2. *Roads for wheeled traffic;* those of the Puna are mainly used for passenger transportation in automobiles. Cart caravans for transport of merchandise along the Chaco border from the Argentine to Santa Cruz. In summer occur interruptions of several weeks; only the Pilcomayo between Sucre and Potosí is bridged. 3. *Trails* used only by pack trains of mules, donkeys and llamas. In the Front Ranges this is the only form of communication but in the other landscapes it is still the most reliable and is the only one when railroads and roads are interrupted after heavy rains.

On the roads Potosí–Sucre, Sucre–Cochabamba, Sucre–Padilla, and Villazón–Tarija have been established regular auto lines subsidized by the government. In winter this means of traffic is reliable, but in the summer interruptions are the rule and there is always risk in undertaking such a journey.

Besides these there are no other real roads in the eastern Puna. The way from Tupiza to Potosí for nearly its whole extent is only a natural trail elaborated by use. It is not much better than the many trails which cross the area in any direction. The traffic on these trails is only possible with saddle and pack animals; mules and donkeys especially are in use (pl. 17*a*). It is only in the western and southern parts where fodder is scanty that the llama appears as a pack animal (pl. 17*b*).

Commerce between areas of similar production.—The exchange of goods takes place even between areas of similar production. With change in elevation the time of the harvest for every cultural plant changes also. As the grain reserves on the heights are nearing their end the crop in the valleys enters the market. A season of failure in one area is likely to be compensated by normal weather and crop condition in another. The consequence is that even the same product is mutually exchanged between two areas in different seasons.

Traffic in every direction is therefore active and products are exported to the mining districts to the west (pl. 14*b*) and are also exchanged between different sections within the same area. Trade is partly in the hands of professional tradesmen. Whole settlements, such as Vitiche, owe their prosperity only to the fact that their inhabitants have learned to take advantage of the difference in prices of certain products in different parts of the area. They buy where there is a surplus product offered and bring it immediately by caravans of pack animals to places where there is an especial demand for it. But mostly each Indian engages in trade with his own product. An Indian of the high plains, for instance, will load his llamas with salt from the *salinas* and bring it in marches of many weeks to the valleys of the east (pl. 17*b*) where he can get about three Bolivian pesos for a llama load. With the help of his family the Indian is able perhaps to care for a herd of twenty to thirty llamas. His trip lasts at least two or three months, and during this time he has to maintain his family and also to pay a small amount for the little pasture he uses when spending the night on one of the large estates. When he comes home after a tiresome journey of some months the result of his commerce is a few small bags of corn and flour.

From the valleys the Indians journey to the settlements of the high plains, sell there their wine, fruits, corn, etc., and bring home wool, clothes, or factory wares. An Indian travels thus many days, often with a single donkey, to sell two baskets of tomatoes or raisins in Potosí or in one of the smaller towns. He offers his produce from house to house in the street of the highland settlement. Everybody sees that he comes from afar and knows that he will certainly not take back his fruits. The money which he gets out of such a bad bargain is immediately given for a piece of linen or for aniline dyes or something else in which the tradesman profits more than the Indian. After a journey of two weeks, he returns home again, unaware of the disproportion between his efforts and their results.

This transport of small quantities of goods from one part of the area to the other is characteristic for all the eastern Puna. Only the unpretentiousness of the Indian and his inability to reckon make such an economic system possible. The traffic on the trails of the eastern Puna is nearly restricted to this type of trade.[38]

Material and Mental Culture

The following section is introduced in the attempt to give an objective sketch of the social *milieu*, without which the cultural geography of the area is scarcely intelligible. A study of distribution of population, of forms of production, and of returns from the land at once shows that these are not simple derivatives from the natural equipment of the area. Material differences in culture among the inhabitants of the eastern Puna are principally expressed in the conditions of the rural Indios as contrasted with those of the white and mestizo population of the towns.

The dwelling of the average Indian is always very primitive; it provides merely the shelter he needs in a severe climate. The space is very limited and the furnishings are most meager. Even table and chairs are wanting; one sits on the ground or on a stone. Since they have no possibility of making comparisons, never having seen better homes, the Indians do not feel uncomfortable in their poor dwellings.

[38] The ordinary traveler who uses them is obliged to employ traveling methods which are neither agreeable nor cheap for anyone who is not a highland Indian, because there is no organization of means of transportation. Even if one gets good animals and a reliable muleteer there is always in the dry season the problem of fodder. In the region of Potosí and Sucre the price in January, 1925, for a quintal (about 100 pounds) of unthrashed rye straw, the daily ration for three mules, was eight to ten Bolivian pesos. When it rains there is more fodder but the rivers then are likely to enforce irksome delays.

Utensils and tools (pl 16*a*, *b*) have not changed much since the time of the Incas; they are simply less well made than they were then. In his dress, the highland Indian is equally conservative. The habit changes from place to place but always shows ancient forms (pls. 14*b* and 17*a*); their most recent fashions date from the Spanish colonial epoch. They use as a rule homespun clothes. The men wear, besides shirt and trousers, the *poncho;* the women wear stiff, voluminous skirts, the glaring colors of which supply the gayest feature in the cheerless landscape and in the not less cheerless settlements. The native dyes are out of use; the highland Indians now use only aniline dyes. Men and women wear the *ojota,* a sandal held by a leather strap.

Lack of cleanliness among the highland Indians provides a distinctive element in the Puna scene. They scarcely wash themselves, or scrub their houses, and even at their feasts and dances the women appear in ragged, greasy clothes. The street scenes give eloquent evidence that the provision of necessaries has been no concern of the people either on grounds of privacy or of sanitation.

The educational level of the Indian population is also very low; few know how to read or write or to check a simple account. They are nominally all Christians but many traces of the cult of their ancestors are still in existence. I have seen the women of a certain village assemble to celebrate the new moon by an elaborate prayer ritual in Quichua. Above all they are superstitious. Every animal one meets is an omen varying according to the direction in which it is going and the time of day. On every pass they deposit as an offering a stone on the *apacheta,* a votive pile that increases more and more with time.[39] At other places they make offerings of small wooden crosses of coca leaves. In reality they have not attained to the cultural state of theism, for they do not believe in gods but are under the sway of a belief in demons, presenting the necessity of propitiating spirits.

The major personal trait is a deep distrust of all their fellow beings. It has certainly its good reason, for their dealings with the whites scarcely serve as an example for honesty among themselves. To the traveler who finds this distrust at every moment it becomes in time extremely repugnant. Even his most innocent questions are answered by evasions. To his first question he receives without exception the response, *"No hay!"*

[39] Erland v. Nordenskjöld, Travels on the Boundary of Bolivia and Argentine, Geog. Journ., vol. 21, p. 518 (1903), investigated such an *apacheta* and estimated the total number of stones which formed it at 50,000.

The following is an instance of a typical conversation with a highland Indian. On the plaza of Padilla stands a house with a sign: "Oficina de correo" (post office). I should like to post a letter and enter. A woman is sitting in the room and I ask her: "Where is the mail dispatched?" She answers: "No hay!" Second question: "Who is the post office clerk?" Answer: "Who may that be?" Third question: "But when comes the clerk?" Answer: "Yes, I wonder when he will come?"

Lack of dependability, indolence, and especially coca chewing and drinking are general. Two experiences with the carnival on the Puna remain unequalled in my memory as to the extent of the debauch in which both men and women indulged, continuing for a week in a state of drunkenness to the oblivion of all else.

A great part of the Indian population still speaks Quichua, but the Spanish language is extending more and more and has now replaced in entire settlements and valleys the original language. The social contrast between Indian and white persists, although an always increasing *mestizo* population becomes intercalated between them. To the Spanish-speaking Indian the descendant of Europeans is still the *viracocha* (literal translation, the creator of the lake) in whose social superiority he believes absolutely. The mestizos, especially numerous in the towns, according to their education and customs are considered either as belonging to the Indians or to the whites, or form the *cholos* (group term *cholada*), an especial social class.

The material and mental culture of the descendants of the Spaniards is different only in grade from that of the Indians. They form strong groups only in the towns. A number of families have remained free from Indian blood but they are the exception. Mixture with Indian blood becomes more and more the rule. The pure whites decrease in number, especially as they do not get reinforcements from outside. The number of immigrant Europeans in the towns of the eastern Puna is negligible. The smaller the settlement the more the Indian and his customs prevail. Only in the somewhat larger towns, such as Sucre and Tarija, are the groups of European descendants so strong that they dominate the general aspect of life and take the leading rôle in the social life of the town. For instance, when a concert begins on the plaza in Tarija or Sucre the Indian policemen first proceed to clear the place of everyone who wears *ojotas* or *ponchos*. Only after this is done does the upper class appear, the whites and mestizos who are considered to belong to it. In dress, the criollos have adopted the European civilization even in its most insignificant details, and follow the changing fashions conscientiously.

But fashion is perhaps the only element of the modern civilization which has been adopted strictly, even in the greater towns. Most of the other customs of life do not differ very much from those of the Indian. One is often quite astonished at the unpretentious and naïve customs of fashionably dressed women and men.

The mental culture of the white population of the larger settlements is a matter of much local satisfaction. Sucre is spoken of commonly as *la muy culta* or *la docta*. Indeed there are in Sucre a university, a geographical society, and other cultural institutions which have to their credit as yet a much larger measure of ambition than of attainment. The white population of the towns of the eastern Puna lives after all in a remote backwater of intellectual life, to overcome which is indeed the greatest problem in the realization of the cultural possibilities of the area.

The whites, descendants of the Spanish conquistadores, have therefore tended to approach in some measure the social milieu of the Indians in the course of time. Little remains of the spirit of enterprise and of the brutal energy which distinguished their ancestors. Instead, the placid life has become the *summum bonum*. Effort is to be avoided, and to earn money by regular labor is a matter that may well be left to the Indio or to the inexplicably restless European.

The social relation between the mass of the Indian population and the white and mestizo upper classes cannot be characterized as an association to their mutual advantage. The Indian is chiefly an object of exploitation, apparently resigned to his fate once and forever. That this resignation is not quite genuine seldom becomes evident. However, the manner in which the highland Indian participated in the civil war of 1898–99 indicates the hatred against white domination which perhaps still lies dormant in the breast of the Indian. Of the Escuadron Sucre, composed of sons of the best families of that city, twenty-seven officers and soldiers became victims of the rage of the Indians. In the church of Ayo-Ayo they were tortured to death. The ordinary appearance of social stability that the area presents may therefore mislead as to the difficulty of reconciling the enormous contrasts that have developed in the social organization of that region.

THE FRONT RANGES OF THE EAST BOLIVIAN ANDES AND THE CHACO BORDER

Structure

The Puca formation.—In the front ranges of the East Bolivian Andes, the Puca formation underlies the greater part of the surface; the lower Paleozoic strata appear at the surface only in form of narrow meridional belts (fig. 4). This condition is the reverse of that in the eastern Puna, where the Paleozoic strata form the predominant structural element and the Puca belts are subordinate strips. Natural oil springs are common in the sandstones and conglomerates of the Puca formation in the East Bolivian front ranges. Its salt beds, evident in the eastern Puna only through the existence of numerous saline springs, appear in the eastern ranges as large masses of commercially exploitable salt. Thus the neighborhood of Entre Rios and Saladillo contains notable deposits of salt.

Orogenic history.—The structure of the eastern ranges presents distinctive features. The effect of strong orogenic pressure directed toward the east is visible throughout. Under the influence of this pressure the Puca strata formed in part normal anticlines.[40] With increased pressure they did not form inverted folds, but broke into great blocks which became overthrust towards the east. Parts of the basal Paleozoic beds also became affected by this *Schuppen* formation. In part, there even originated a most complex, small-scale imbrication (*Quetschzone*) in which the Mesozoic and Paleozoic strata are so many times repeated that one must imagine an extraordinarily thorough smashing and slicing of the crust. The adjoined profiles (fig. 3) represent these structures in schematic form. In reality the structure is much more complicated. Many observed structural details cannot be represented on account of the small scale of the profiles, but many details also are likely to escape observation as they are hidden under the dense vegetation which covers large parts of the front ranges of this part of the Andes. Only at favorable places, as in stream beds and on steep slopes where the growth of vegetation is checked by the surface, is one likely to find good outcrops. Observations on the structure of the area therefore must be generalized by means of liberal interpolations.

[40] Walter Schiller, Contribución al conocimiento de la formación petrolífera de Bolivia, Revista del Museo de La Plata, vol. 20, pp. 168–197 (Buenos Aires, 1913).

Whether the orogenic movements which formed the front ranges took place in the first or in the second period of Andean movements, is as yet undecided for the area as a whole. The older series of Puna Fill was formed during the interval between the two Andean orogenic movements. It supplies, therefore, central evidence on orogenic history but is locally of limited distribution. Where I saw the deposits at the foot of the eastern border range in the Serranía de Aguaragüe, near Villa Montes and Machareti, they dip to the east in conformity with the Puca strata. They are here more strongly dislocated than in any other place seen (fig. 3, profile A).

This apparent conformity of the dislocated Puca with the older series of Puna Fill suggests that the Andean orogenic movements of the second period were responsible at least for the structure of the extreme eastern ranges. That these movements are still going on is indicated by the frequent earthquakes which affect the settlements of the Andean foothills.

In disconformity with these dislocated sediments are the horizontal Chaco deposits, which enter also the large eastern structural depressions between the front ranges.

The Land Forms of the Front Ranges of the East Bolivian Andes

Contrast to Puna.—The striking difference between structure of the Puna and the front ranges finds also its expression in the land forms of both areas. The limit between these two morphologic areas is sharply drawn, not a blurred zone as between the Puna proper and the eastern Puna (fig. 5). The brusque change of the land forms does not even escape the eye of the native, perhaps because it has a strong influence upon the grade of the trails; on the way from the Chaco to Sucre I was told of the place where I should come to the *caminos llanos,* level roads, several days before I got to it. Although this term *llano* turned out to have only relative value, the point indicated did coincide exactly with the structural limit between front ranges and Puna. It was not far west from the Rio Acero where the most eastern border of the Paleozoic Puna block is thrust over the last great Puca block (fig. 3, profile B).

The ranges.—The singular structure of the front ranges is reflected truly in its land forms (fig. 2). The *Schuppen,* overthrust toward the east, form morphologically long, narrow hogbacks which extend in meridional direction for hundreds of kilometers. Their heights

change little and remain mostly between 1500 and 2000 meters (pl. 19 and fig. 5). On the way from Tarija to the Chaco one crosses nearly a dozen such ranges. The gradient of the slopes changes with the dip of the strata. Steepness of slope, together with the argillaceous cement of the rocks and periodically heavy rainfall, makes landslides a common and characteristic phenomenon of the landscape in spite of the luxuriant vegetation.

The great valleys.—The meridional depressions extend between the ranges. In the west they form deep valleys, but toward the east they become continually broader, often many kilometers in width, so that there can be no doubt about their orogenic origin. Their bottom is then flat and covered by the same fine deposits which form also the soil of the Gran Chaco. Morphologically the Chaco does not find its western limit at the foot of the eastern front ranges; it penetrates between the mountain ranges, the surface of the large meridional depressions of the eastern part of the ranges still showing its typical form.

Morphogenesis.—The land forms of the front ranges appear to be largely structural.[41] The elevations of the ranges and the existence of large depressions between them are due to orogenic forces. The river courses are largely determined by structure. They run mostly in synclinal valleys (pl. 18*b*) from north to south or from south to north. The greatest modification of the structurally determined land forms exists where a river breaks across one of the ranges by a cañon (pl. 20*a*). These typical erosion valleys in their present form have all the characteristics of recent origin; they are still so narrow that not even a trail is feasible. The river fills the whole bottom of the valley and the slopes are nearly vertical. The following views as to their origin may be considered: (1) These narrow transverse cañons might suggest an antecedent origin; I found however no evidence to support such suggestion. Neither fluvial accumulations nor erosion terraces were observed in any of them; a negative fact which of course does not exclude the possibility of antecedence. (2) An explanation

[41] I cannot follow K. F. Mather, Front Ranges of the Andes, *op. cit.*, p. 727, in his interpretation of the land forms of the area. Some small leveled plains, the most extensive of which is cited with a surface of "one square mile," and the "close accordance in summit level within each mountain group" form, as I see it, not sufficiently strong evidence to permit the hypothetical construction of peneplanation of the entire East Bolivian front ranges. The idea that the extensive interior depressions are "wide valleys quickly carved out in the area of weaker rocks" makes rather heavy demand on stream erosion. But the hypothesis must be considered still more inadmissible since there has not been presented sufficient evidence to prove that the extensive depressions coincide with areas of weaker rocks.

of the morphologic difference between the broad north–south depressions and the west–east gorge-like valleys has been proposed as being caused by differing resistance of rock material (see footnote 41). There is not sufficient evidence that the hydrographic net was originally developed on a partially graded plain which later became uplifted. It is evident that no differentiation in rock resistance caused the contrast between the broad meridional depressions and narrow transverse cañons. The meridional depressions, some of them several kilometers broad, do not represent areas of weaker rock material, which might have been easily removed, in contrast to the transverse cañons hypothetically conceived as developed in more resistant rock material. In part the longitudinal valleys are heavily filled with detritus. Where evidence is available as to the material in which they are formed, the Puca formation appears to be the bedrock of valleys and ridges alike. (3) It seems rather as if the cañons which cut through the different East Bolivian front ranges are the effect of regression. Every one of the front ranges has its lower erosion basis (the level to which erosion may proceed, or local base level) at the east, gets greater rainfall on the eastern slopes, and where the ranges are of hogback type the eastern slope is the steeper one. In all the eastern front ranges area erosion is thus favored on the eastern slopes and in different localities it is possible to observe the removal of the watershed from its original place on the general crest of the range to the western slopes. The different stages of the probable formation of a transverse cañon (*Durchbruchstal*) are thus accessible to direct observation. An especially interesting instance is furnished by the Rio de Cuevo west of the little town of the same name. The watershed has here been removed from the heights of the Sierra de Mandiyuti to the lower part of the western slope of this range so that the range is nearly cut through by the Rio de Cuevo (see itinerary).

Hydrography

By far the larger part of the front ranges is drained by the Pilcomayo; the systems of the Bermejo and the Parapiti are of comparatively minor importance.

The stream pattern.—The hydrographic net is of the trellis type, the direction of the river courses changing between meridional and west–east stretches. The erosion differs greatly in these different parts of the course. In the meridional parts the longitudinal profile

is largely compensated, the rivers are broad and of slight depth, and broad valley floors accompany the stream bed on both sides. In the west–east parts of the valley the depth is sharply increased and the breadth similarly decreased (pl. 20*a*). The rapidly running water here elaborates deep and unusually large potholes into the rocky bed. They are often several meters deep and so broad that they occupy the whole diameter of the bed in the case of some of the smaller rivers. In the Quebrada de Machareti and also in the Quebrada de los Monos exist such holes in which water and sand remain even when the river bed dries out. Travel through these cañons may therefore be impossible or at least very difficult at all times. The great velocity with which the streams cross the ranges from west to east gives them great ability to transport solid material. For the *Pirapo* of the Pilcomayo, that part of its course which crosses the Sierra de Aguaragüe, a kind of breakers (*Wallung*) in the stream is typical. The waves are more than a meter high and are caused by the formation of temporary bars during rises in the river, apparently when the movement of great masses of coarse sediment has begun on the cramped stream floor, but before it attains to such a flood stage as to enable it to sweep out its bed freely. Such conditions are developed at Villa Montes so strongly that they become dangerous for stout boats, and even the Chaco Indians, although they are excellent swimmers, are afraid of them.

Regimen of the rivers.—The seasonal distribution of the rainfall in the front ranges as well as in the eastern Puna is well reflected in the regimen of the rivers. The rainy period from December to March is also the time of the *crecientes,* the high floods. The dense forests are of no visible influence upon the regulation of stream flow. The absorption of the forests does not make up for the sharp increase of rainfall. The periodical oscillations are generally very great. The greater rivers show marked periodic oscillations of their level; in winter they have but a minimum of water and all of them may occasionally dry out in that season. But while it is the rule that the small creeks dry out, this phenomenon becomes less and less frequent the greater the river. It was reported to me that the Pilcomayo, at Villa Montes, was for the last time without running water in its bed some ten years ago.

The *crecientes* of the rivers of the front ranges show the same differences, but they are everywhere of high importance to human life in the region, especially to traffic. Even the bed of the smallest, most

intermittent creek can hold a torrential river after heavy rainfalls. The threat of flood in a small creek valley is always announced to the traveler by the beginning of rain and he has time to bring himself and his pack train into security. However, the flood of such a small creek does not last much longer than the rain itself. Such creeks form therefore, even during the rainy season, no serious obstacle to the traffic; they detain the traveler for some hours or at a maximum for a day or two.

The greater the river the longer the periods of high floods and the more unannounced the arrival of the *creciente*. These flood waves which come from great distances without any previous local indication are often very dangerous and demand their victims annually. When the rainy period has once begun and the first flood comes down the river bed, the greater rivers show a continual sharp fluctuation of level for the duration of the rainy season. Every rainfall in any part of the extensive drainage area causes a new flood wave. The fords of the Pilcomayo, Parapiti, and the Acero are at that time often impassable for many weeks, forming thus a great obstacle to traffic of every kind.

Erosion and transportation of sediment by running water are under the rule of these periodical changes of volume of the rivers. Especially striking are the enormous masses of suspended material which make the rivers and creeks turbid during the time of the *crecientes*. The turbid aspect of the water is the best sign to the traveler that the volume of the river is above normal. When the water is not clear he has always to count with the possibility that the fords are impassable. The flood waters of the front ranges have a red brown color derived from the Puca sandstones.

The Climate of the East Bolivian Front Ranges

Rainfall.—The climate of the East Bolivian front ranges differs from that of the Puna in the west as well as from that of the Gran Chaco in the east. The distribution of the rainfall through the year here as well as in the neighboring areas is typical of the outer tropics, with one rainy season in summer and one dry period in winter. The precipitation, however, is far more abundant than in the lowland of the Gran Chaco where no mountains cause the ascent of the wind, and is also more abundant than on the Puna where the southeast winds arrive strongly reduced in moisture. The annual rainfall is

very considerable in the East Bolivian mountain ranges, the rain coming mostly in the form of cloudbursts. Rainfall during the evening or the night is here the rule as well as in the Chaco. There exist no observations which would allow one to express numerically the annual amount of rainfall in the East Bolivian front ranges; Fiebrig estimated it at 1800–2000 mm.;[42] on the basis of information from the natives it would appear however that the annual variability is everywhere much more than 200 mm.

Instrumental observations of a longer period exist only from Villa Montes,[43] (fig. 12), situated at the eastern foot of the most easterly of the front ranges where the Pilcomayo enters the Gran Chaco.

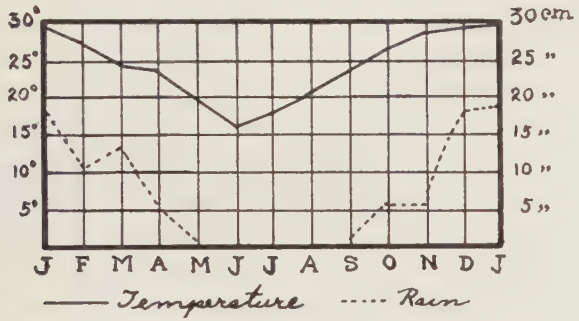

Fig. 12. Climate of Villa Montes.

These observations prove that the variation in the annual amount of rainfall is great. The average rainfall in the years 1914–1924 was 904 mm.; varying from 660 mm. as a minimum in 1924 to 1106 mm. as a maximum in 1915. On the Chaco border as well as in the East Bolivian front ranges themselves the variation of total rainfall, as well as the shifting of the beginning of the rainy season, are of high economic importance. Every year the inhabitants of these regions await the first rainfall anxiously. It happens occasionally that the rains begin so late as to make it impossible to sow. The summer rains begin usually at the end of October or in November, but often as late as December. They are most abundant in January, decrease in February, and become irregular in March, the last rains coming in April. Several months are as a rule without any rain. In Villa Montes the years 1913–1924 had on the average three absolutely dry

[42] *Op. cit.*, p. 63.

[43] The unpublished meteorological observations in Villa Montes have been carried out in the years 1913–1925 by the late German Consul, Carl Pflanz, who kindly put the records at my disposition.

months, but in certain years the dry season is far more extensive. For instance it rained at Villa Montes in April, 1922, 2 cm., then followed six months without any rain, and only in November the rain began again with a total of 8 cm. In December of the same year the real rainy season commenced with 32 cm. In Villa Montes very heavy rainfalls have been observed, at the maximum, 19 cm. in one day.

Temperature.—The areal distribution of temperature is far less uniform than that of rainfall. The differences depend less upon the latitude than upon the altitude of the place. The East Bolivian front ranges consist of more than a dozen meridional depressions, of which the most eastern ones are the lowest. They are separated from each other by continuous ranges. Every one of these isolated valley-landscapes is distinguished climatically also from the neighboring one, although this difference is often not considerable. In the eastern valleys the winter is so mild that frost is rare, whereas the summer becomes just as hot as on the Chaco border, the temperatures of which are known at least for Villa Montes. Temperatures as high as 46° C in the shade have there been observed in the warm season. Even the winter months still show high temperatures during the day. The table below gives for the years 1914–1918 the average number of days with a temperature of 31° C and over:

January	27	July	4
February	18	August	10
March	15	September	19
April	11	October	21
May	2	November	26
June	1	December	27

Frost is rare; in the years 1914, 1915, 1919, and 1920 the thermometer at Villa Montes scarcely reached zero Centigrade. In 1918, however, frost was observed in the months of June to September on ten days with —3° C as the minimum. Although frost is rare in the region of Villa Montes it comes sufficiently often to make the successful cultivation of tropical plants, such as coffee and bananas, impossible.

Humidity.—In the moist forests of the East Bolivian front ranges the high relative humidity of the air, combined with high temperatures makes the summers disagreeable to the North European. In the lower parts of the forest land the stifling heat keeps him in a continuous state of discomfort. Any kind of physical effort starts up perspiration immediately, but without reducing sensible temperatures

appreciably since evaporation is insignificant in the moist air, especially too since the air movement is slight in the dense forests. Fatigue and exhaustion overtake one quickly under these conditions.

It is therefore much more tiresome to cross in summer the many but not very high ranges of the East Bolivian front ranges than to ascend one of the high Puna mountains in the west. Soaked by perspiration and rain the traveler finds not the least refreshment in the very moist air. The physical exertions which traveling brings with it mean therefore a great expenditure of energy. Only when he comes again to the heights of the Puna does the greater absorption of warmth, increasing with the height, give him once more the feeling of refreshment, which immediately invigorates his energies and augments his physical capacities.

Since the floors of the structural longitudinal valleys descend gradually from an elevation of about 1800 meters in the west to about 900 in the east, and the ranges between them seldom exceed 2000 meters, there exists nowhere in the East Bolivian front ranges the prejudicial effect of the high altitudes which causes mountain sickness. The climatic conditions, however, favor malaria which is common locally.

Climatic change.—The only data which might be interpreted as a suggestion of recent climatic change were observed between Cuevo and Monte Agudo. Between these two settlements the trail runs through a dry river bed, which in January did not even contain traces of water and is reputed as permanently without a stream. Near this dry river bed is situated a small, scattered settlement which has the rather remarkable name of Pirarenda (*pira,* fish; *renda,* a place where there is plenty). As the Chiriguanos select very appropriate place names as a rule, it would be an odd exception for them to give such a name to a place where there is no water. It seems to be almost beyond question that the name preserves the record of a former condition. The question, however, is one which raises a problem that could not be fully investigated: Was the river dried out as the climate changed, or is there some other unrecognized cause as, for instance, the decapitation of its upper course, or some other hydrographic change apart from climatic change?

Plant and Animal Life in the East Bolivian Ranges

Vegetational contrast to Puna and Chaco.—The East Bolivian front ranges are distinguished by their vegetation from the neighboring landscapes. The moderate heights of its mountains, the copious rainfall, and the warm temperatures are the chief natural factors which find their expression in the plant cover. The character of the soil causes only local modifications. Luxuriant, moist forests cover the slopes of the ranges and, in the western part of the area, also the bottom of the valleys. The general width of the forested mountains is more than 100 kilometers on the average. The limit coincides in the west nearly exactly with the geological border between Puna and the East Bolivian ranges, not so much because the prevalent belts of the east result in a contrast in soils as because this geological limit also stands out orographically and climatically in a very pronounced form: in the west the high Puna, the plains of which are situated at 3500 meters and in the east the front ranges which scarcely pass the 2000-meter level at their highest elevations.

Mountain forests.—The character of the East Bolivian forests is not typically that of the humid tropics, the dry season being too pronounced. Drought continues at times so long that the forests dry out and are destroyed by fires. Rainfall is so abundant during the rainy season that a sufficient saturation of the ground takes place permitting vegetation as a rule to survive the dry season without an especial xerophytic adaptation. In the rainy season this woodland with its many liana-like creeping plants makes quite a tropical impression (pl. 20*b*).

Floristically these mountain forests form a part of the great Brazilian province from which they are separated only by the Chaco plains, prevalently covered with different floristic elements.[44]

In places deep green meadows lie in the midst of the moist mountain forests. Soon after the beginning of the rainy season these become excellent natural grazing grounds. But mostly the grass is mingled with numerous plants of one of the compositae, the *romerillo* (*Baccharis*) which diminishes considerably the value of these grazing grounds. The romerillo is an annual and very poisonous plant, resembling alfalfa in its earlier stages, which grows quickly after the first rains. It is a foot or more high when the grass around it begins

[44] Th. Herzog, Die Pflanzenwelt der bol. Anden, *op. cit.*, p. 110.

to sprout. Imported animals in particular are likely to eat it, death within twenty-four hours usually being the consequence. It is a major danger and source of apprehension especially for the traveler in camp who does not as yet know the plant. Inexperienced animals must have their mouths tied up during the march in order to protect them.

Coniferous and alder forests.—The humid forests ascend on the slopes of the ranges to a height of approximately 1800 meters. In the western part of the area, with increasing height and corresponding decrease in temperature, the composition of the forests is changed notably. At approximately 1800 meters coniferous *pino* (*Podocarpus* sp.) appears first as isolated specimens but at higher elevations forming extensive forests (pl. 21*a*). In the shadow of these moist and evergreen coniferous forests a luxuriant plant life develops which consists of herbaceous plants, among them many ferns. Near the upper limit of this forest, there appears the *aliso,* an alder, often six to eight meters high and frequently covered with parasitic plants on the order of Spanish moss (*Tillandsia usneoides* and others). These alder forests form the upper margin of the pinos vegetation and pass at higher altitudes into the alpine meadows. Alder and pine forests form together only a narrow belt, which defines the upper border of the mesophytic, subtropical forests along the upper limit—as a rule being at 2400 meters.

Monte.—The mesophytic mountain forests cover heights and valleys uniformly only in the west. In the eastern longitudinal depressions, as for instance in those of Chimeo and Cuevo, permeable and therefore mostly dry Chaco deposits compose surface and soil. This different character of the soil finds also its expression in the vegetation. It becomes typically xerophytic, as in the Gran Chaco itself. The predominant vegetation formation is a dense bush: the argentine *Monte* with the Quebracho, the Chañar, the Palo borracho (pl. 21*b* and 22*a*), and other hardwoods. The grass which grows in their shade sprouts rapidly after the first rains. In a few weeks the seeds ripen, and when the arid season begins they dry up again.

The Settlement of the East Bolivian Front Ranges

The Chiriguanos.—The history of settlement in the East Bolivian ranges is quite different from that of the Puna. Indians, speaking Guaraní, came from the upper Paraguay and occupied this region at least by the middle of the fifteenth century, according to Garcilasso de la Vega and Sarmiento de Gamboa, the first chroniclers. A connection with the parent stock in Paraguay seems to have been maintained long after.[45] We know that they received considerable reinforcements even in the first half of the sixteenth century.[46] The name of Chiriguanos has evidently been given to them as a contemptuous nickname by the Quichua-speaking Indians of the highland (*chiri,* cold; *guano,* dung, in Quichua); in their own language[47] they call themselves *avas,* men or masters. The Chanés, who are Aruaks, live among the Chiriguanos and are perhaps the remainder of an older conquered population. The Chanés have adopted the language and the customs of the Chiriguanos, only a few of them still using their old language.[48]

Until the beginning of the seventeenth century, the Chiriguanos maintained their independence very successfully and defended the East Bolivian ranges against the Indian highland dwellers to the west and also against the Spaniards, recently conquerors of Perú. "The doctrine of the King Incas never reached them" and "they were not conquered" reports Garcilasso de la Vega.[49] It is, however, impossible to get a clear idea of cultural conditions at that time in the East Bolivian ranges on the basis of the few existing historical data. It is evident that the wild forests of the east made quite a sinister impression upon the Indians of the highland, the landscape of which (Inca Garcilasso de la Vega[50] says that it was execrable), being covered with dense forests, morasses, and lakes, seems to have repelled the highland Indians. The forest Indians themselves, the Chiriguanos, must have inspired them with fright too. Sarmiento de Gamboa

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[45] Bernardino de Nino, Etnografía Chiriguana, p. 69 (La Paz, 1912).

[46] E. v. Nordenskjöld, The Guaraní invasion of the Inca empire in the sixteenth century: An historical Indian migration, Geogr. Review, vol. IV (1917).

[47] D. Giannecchini, Reglas elementales de la lengua chiriguana para el uso de los RP. PP. Misioneros Franciscanos etc., Lucca (1896). *Idem,* Diccionario Chiriguano-Español y Español-Chiriguano etc., Tarija (1916).

[48] E. v. Nordenskjöld, "Indianerleben," *in* El Gran Chaco, p. 157 (Leipzig, 1913).

[49] Garcilasso de la Vega, *op. cit.,* vol. I, chaps. 10 and 12.

[50] Garcilasso de la Vega, *op. cit.,* vol. VII, chap. 17.

describes them as "a nation of the forests, naked and eaters of human flesh, for which they have a public slaughter house."[51]

Inca Yupanqui was the first who resolved to conquer them. This must have been about the middle of the fifteenth century, his rule as the tenth Inca extending from 1397 to 1464 according to the chronology of Sarmiento de Gamboa.[52]

> With this object, the land being hitherto unknown, he sent spies, who examined the country and its inhabitants. . . . They reported that the natives were worse than wild beasts, and without any religion, laws or human customs, having no houses and eating human flesh. They made inroads into the neighboring districts, and ate all they captured, without respect for sex or age, drinking the blood of those they beheaded, that they might lose nothing of their prize. They not only ate the flesh of their enemies, but also that of their relations who died. . . . They went naked, and in their cohabitation made no difference between sisters, daughters, or mother: and this was the usual mode of life among the Chirihuanas.

Probably the Chiriguanos were not even at that time quite so bad as Garcilasso de la Vega paints them; his story appears to possess the emotional coloration of the propagandist, for he goes on to say:

> The good Ynca Yupanqui having heard this report turned his face and spoke as follows: Now our obligation to undertake the conquest of the Chirihuanas is stronger than ever. We are bound to deliver them from the bestial and vicious state in which they live, and to teach them the life of men; for this our father the sun has sent us.

This first attempt however failed, although an army of 10,000 men was sent out. Such was probably the immediate occasion for the construction of the fortress of Incahuasi, the ruins of which are still existing on the heights west of Lagunillas.

> But at the end of two years, they came forth without having accomplished the undertaking, owing to the great store of morasses, swamps, lakes, and dense forests. The Spaniards, as well as the Yncas, were unable at least during the first part of the colonial period to subdue the Chiriguanos.[53]

The first Spaniard to attempt the task with a well-equipped army was the Viceroy Don Francisco de Toledo. In 1572, he

> entered the province of the Chirihuanas; but in a few days he learnt the difficulty of the undertaking by experience. . . . The Viceroy came back as a fugitive, having left behind all he had taken with him, that the Indians might be satisfied with their captures, and leave him to escape. He came out by so bad a road that, as the beasts were unable to drag the litter in which he traveled, the Spaniards and Indians had to carry him on their shoulders. The Chirihuanas followed behind, with derisive shouts, and cried out to the bearers to throw that old woman out of the basket, that they might eat her alive.[54]

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[51] Sarmiento de Gamboa, op. cit. chap. 51.

[52] Sarmiento de Gamboa, *op. cit.*, p. 258.

[53] Lorenzo Suarez de Figueroa, Relación de la ciudad de Santa Cruz de la Sierra *in* Relaciones Geográficas de Indias, vol. 2, pp. 165, 166 (Madrid, 1885).

[54] Garcilasso de la Vega, *op. cit.*, chap. 17.

European penetration.—Since the end of the seventeenth century, the influence of the white man, the *caraï* or *caraï pochi* as the Chiriguanos call him (*caraï*, oppressor; *pochi*, bad) began to penetrate into the East Bolivian ranges. Since then cultural conditions in this landscape have developed slowly to the form in which we know them. This European penetration took place chiefly in three different forms. (1) Whites and half-breeds from the neighboring areas advanced as settlers and especially as merchants, step by step into the interior; (2) military posts became established to protect the settlers and to make punitive expeditions against the Indians when they were recalcitrant; (3) missionaries established themselves wherever there existed an Indian settlement of importance. It is difficult to evaluate the part of each of these three factors in the final conquest of the East Bolivian ranges, which was accomplished in the last years of the past century. The peaceful penetration by merchant and colonizer has found not a single historian; very little is known about the share that the military forces took in the enterprise; but the missionaries were from the beginning their own chroniclers and have left a fairly abundant and somewhat voluble literature about their work.[55] Although their influence was a very considerable one, the fact that it is well documented causes it perhaps to stand out too prominently.

The European penetration into the forest of the Chiriguanos started from two chief points. In the northeast of the East Bolivian ranges is situated the little town of Santa Cruz de la Sierra. Its foundation antedated the local arrival of the conquistadores from Peru, who at that time had not yet crossed the land of the Chiriguanos. Santa Cruz was founded in 1560 by a Spaniard, Nuflo de Chaves, coming from Asunción. The inhabitants of Santa Cruz had nothing to do with the christianization of the Chiriguanos, but their sphere of influence as merchants and colonizers reached and reaches still some 300 kilometers to the south. The first white inhabitants of Cuevo are reported to have been all Santa Cruzeños.[56] Another not less important starting point for opening the area to European influence was Tarija, to the southwest. From this town started not only the ordinary colonization under military protection, but the Colegio

[55] El Colegio Franciscano de Tarija y sus Misiones. Noticias históricas recojidas por dos misioneros del mismo Colegio (Quaracchi, 1884).

Bernardino de Nino, Etnografía Chiriguana (La Paz, 1912); Las Misiones Franciscanas del Colegio de Propaganda fide de Potosí, 2 vols. (La Paz, 1918); Guia al Chaco Boliviano (La Paz, 1913).

[56] B. de Nino, Etnografía Chiriguana, *op. cit.*, p. 91.

Franciscano de Tarija became also the most important point of departure for missionaries. Even the Franciscan monks of Potosí came to their missions mostly via Tarija. Actually these two towns, the first situated in the low plains east of the Andes and the second in the dissected Puna, still dominate the cultural scene in the East Bolivian front ranges. The influence of Sucre is far less important, especially since the trail which goes thence to the land of the Chiriguanos has to cross not only the deep Rio Acero but also several exceedingly steep hogbacks (pl. 19) and is often impassable. From Santa Cruz de la Sierra and from Tarija the caraï freely penetrates into the forest of the Chiriguano and on the other side the Indian himself tries now to leave his country by another route. Along the eastern border of the Serranía de Aguaragüe runs the trail to the sugar country in the neighboring Argentine by which he migrates to better living conditions, *bapurenda* (where there is much work) as he calls it.

The first who tried to convert the Chiriguanos were the Jesuits. Their work in Paraguay and in the Llanos of Mojos and Chiquitos had given an extraordinarily good result. Their attempts to convert the Chiriguanos failed absolutely, however. In the hope of civilizing the Chiriguanos, always hostile to the Spaniards, they have neither spared their labor nor their lives; five of them "were butchered by these savages," reports the Jesuit Döbrizhoffer,[57] without claiming the least success.

In the first decade of the seventeenth century the work of the Franciscan missionaries began. They too had to overcome strong resistance and many reverses before they obtained real success. The Chiriguanos became really subdued by the Bolivians only at the end of the past century, their last revolts occured in 1875 and 1892. During the latter, the town of Cuevo and certain other villages were totally burnt down, and on the plains of Boyuhibe on the border of the Chaco, the Chiriguanos five thousand strong gathered for their last battle against the caraï.

The Chiriguano is still actually the chief inhabitant of the East Bolivian ranges. He found the environment which suited him in these forests. There was water for his household needs (including, be it noted, a daily bath) and enough to cultivate his Indian maize without irrigation. Never exclusively a hunter and collector of wild

[57] Martin Döbrizhoffer, Historia de Abiponibus etc. (1784). English translation, An account of the Abipones, vol. 1, p. 46 (London, 1822).

fruits, the Chiriguano always maintains agriculture as an essential industry. His living habitat is therefore nearly restricted to the East Bolivian rainy forests.[58] He exceeds these haunts only along the rivers flowing into the Chaco and even this displacement is at least partially due to fear of the whites, who crowded him from his original home. Along the border of the Gran Chaco they live in contact with other Chaco Indians or in the missions, often in mixed settlements. But the Chiriguanos do not intermarry with others since they consider them inferior. The Chaco Indians for their part nowhere pass west of the Serranía de Aguaragüe. Only in the past years, a slow immigration of whites, highland Indians, and Cholos begins to get into the area, chiefly for purposes of trade.

Depopulation of the area.—The contact with European civilization has had no favorable effect upon the inhabitants of the East Bolivian ranges. Although it is rather difficult to get a clear idea of the number of the Chiriguanos in past times, it seems to be a fact that their number has decreased strongly in the past century. In 1586 Figueroa estimated the number of their warriors in all the Cordillera at only four thousand,[59] whereas P. Lozano gives the number of the Chiriguano warriors at the beginning of the eighteenth century as twenty-five thousand,[60] in which case their total number must have been about two hundred thousand. At the beginning of the past century, there were more than twenty-three thousand living in the missions of the Franciscans and the total number was still estimated roughly around two hundred thousand. In 1910 their number was only about twenty-five thousand.[61] Whole settlements which once were flourishing are now disappearing. Chimeo (pl. 23*a*), for instance, in 1883 still had 143 inhabitants but contains now only one family. The Mission of Machareti shortly after its foundation in 1869 had three thousand inhabitants, in 1912 only fifteen hundred.

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[58] J. B. Vaudry, Carte des limites habituelles de l'habitat des Chiriguanos, *in* Arthur Chervin, *op. cit.*, vol. 1 (Paris, 1908). The eastern limit of the area occupied by the Chiriguanos has been traced on this little map in a too schematic way and is therefore unreliable.

[59] Relaciones Geográficas, vol. 2, p. 167. "La cantidad de los Chiriguanos que habrá en toda la Cordillera me certifican los que más la han andado y visto y los indios que han estado captivos entrellos, que será cuatro mil indios de guerra."

[60] Padre Lozano, Descripción chorográfica etc., del Gran Chaco Gualamba etc., *in* B. de Nino, Etnografía Chiriguana, p. 78 (Córdoba, 1733).

[61] B. de Nino, *op. cit.*, p. 77, estimates their actual number at twenty-six thousand. Vaudry, *in* Chervin, *op. cit.*, vol. 1, p. 82, gives their number as twenty to twenty-five thousand. Thouar, A., Explorations dans l'Amerique du Sud à la recherche des restes de la mission Crevaux (Paris, 1891), certainly underestimated their number in giving it only at seven to eight thousand.

A number of causes result in the continual depopulation of this area which because of its natural riches should justify a considerable development. The natural increase of population is small[62] and the intensification of the trade brought with it a quick and general propagation of diseases. Malaria is endemic in many places. Whooping cough and especially smallpox epidemics have taken heavy toll among the Indians. The Mission San Pascual de Boicovo, founded in 1875, had in the first period of its existence twelve hundred inhabitants. In 1880 three hundred of them died from smallpox; in 1894 from the same disease, 94; and in 1895, 45. The number of inhabitants in 1912 was about three hundred. Along the eastern foot of the ranges the carters who bring merchandise from the Argentine railroad to Santa Cruz de la Sierra have disseminated sexual diseases widely among the Indians.

Excepting the missionaries, the white and half-breed immigrants into the area contributed little or nothing to increase the welfare of the original inhabitants. In general, they applied the same methods of exploitation which were familiar to them since the Spanish colonial times. During the rubber boom in the forests of northern Bolivia they even sold the Indians of the front ranges into the tropical forest, from which they never returned. High taxes also destroyed several forms of cultivation such as that of tobacco. The oppressive economic situation is cited by the Indians as the direct cause of the strict birth control that is practiced.

The economic condition is aggravated by the fact that the area joins at the south with the Argentine province of Jujuy, which enjoys a much more active economic life as part of the progressive Argentine republic. The sugar manufactories of Jujuy always need hands, especially during the harvest. Good wages in the sugar country draw the inhabitants from the farthest East Bolivian ranges. Although the Chiriguano is very much attached to his native place this temptation is too strong and considerable emigration, especially of the young and more robust men takes place continually. Depopulation thus goes on continually, although the land is rich enough to support a numerous population.[63]

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[62] Padre B. Nino, *in* E. v. Nordenskjöld, Die Bevoelkerungs Bewegung unter den Indianern in Bolivien, Petermanns Mitteilungen, 1917, p. 108–112, gives the number of children of twenty normal Chiriguano women of Santa Rosa and Ibo (108) as five per family, of these 108, 58 died.

[63] The dream of Francis Burdett O'Connor, once lieutenant colonel of the Irish legion in the South American War of Independence and later on resident of Tarija, to found in the East Bolivian forests "the colony of New Erin as green,

Types of settlements.—The cultural landscape of the East Bolivian front ranges is quite different from that of the heights and valleys of the Puna. The Chiriguanos never formed one great community nor did the environment favor the formation of greater settlements. They lived in small tribes, never more than forty families together, in a village under the direction of a *tubicha* (chieftain) or "squatted" in the forests, especially on the broad valley floors of the large meridional valleys. Besides the village the isolated ranch is still a common form of settlement, although the missionaries tried always to bring the people together in large missions. In certain valleys, as south of Monte Agudo, the number of ranches is large, whereas in other parts of the area one has a long day's march to come from one ranch to the next.

The Chiriguanos build a type of house different from that used by the highland Indians. Their original large house occupied by several families has absolutely disappeared, as well as the more primitive round house. De Nino[64] saw still, in 1905 near Tiguipa, three tribes living in round houses with conical roofs detached from the wall. The type of rectangular house which they now use is of more modern date. It is nothing but an imitation of the houses which the whites from Santa Cruz build. Every house has only one large room. They first drive four corner posts in the ground. The roof is thatched with straw and has a very steep pitch. No stones are used for the walls but only horizontal bamboo stakes which are tied to the posts by lianas (pl. 24*a*). When the first rain comes the inhabitants prepare mud with which they fill up the intervals between the bamboo stakes. The roof extends about five feet beyond the front of the house and forms thus a small veranda in which the family lives mostly[65] (pl. 24*a*).

At some distance from the house are the sheds where they keep the corn. These barns are built in the same way as the dwellings, but are still loftier. They never stand directly upon the ground but on

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fertile, and flourishing as our poor old native land," has never been realized although over a hundred years have elapsed since he directed his proclamation to: "The people of Ireland!"—E. Temple, *op. cit.*, vol. 2, pp. 390, 391.

[64] B. de Nino, Etnografía Chiriguana, p. 169.

[65] This type of house was already of general use in the first half of the past century. Weddell, who visited the region of the Chiriguanos in 1845–46, says about their dwellings: "Les habitations de ces Indiens sont assez bien faites. Toutes sont sur le même plan: elles consistent en une grande chambre carrée dont les murs, assez bas, sont construits en bambous ou en goue; le toit est de chaume." Expédition dans les parties centrales de L'Amérique du Sud, de Rio de Janeiro a Lima, et de Lima au Para; sous la diréction de Francis de Castelnau. Histoire du Voyage, vol. VI, p. 56 (Paris, 1851).

posts one to two meters high, like pile dwellings (pl. 24*b*), a fashion that is repeated in American corn cribs and in part for the same reason, namely the ventilation of the maize.

The houses in the Indian villages are identical with those which are scattered in the forests. Only a small number of Indian settlements remain in their original condition free from European influence. Important Indian settlements soon attracted the attention of the missionaries and the presence of a mission always changed the general aspect of the settlement. The ground plan was made rectangular and the houses were constructed in quite a uniform way (pl. 22*b*). The mission structures themselves, church, school, and dormitory of the monks, immediately changed the general aspect of the settlement. The missions are of superior construction, mostly of adobe and thatched with red tiles. Situated on an elevation and overlooking the Indian dwellings they form the natural center of the settlement just as the castle of the feudal lord did in many old European towns. The mission, as well as the castle, belongs to a past time. Their flourishing state is over and they are in continual decay. Not only did the Bolivian government secularize several missions such as San Antonio (pl. 24*a*), San Francisco, Chimeo (pl. 23*a*) and Itau, thus accelerating strongly their natural decay, but the existing missions have also become affected by the general decline of culture in the East Bolivian front ranges and the number of Chiriguanos who live in missions decreases with that of the Indian population in general.

Urban settlements.—Another type of settlement is found in the small towns such as Entre Rios, Cuevo, Monte Agudo, and Lagunillas. They must be considered as urban settlements not so much on the ground of the number of their inhabitants, which is very restricted, but for their professional structure which distinguishes them from the usual Indian villages. Situated in the midst of a cheerful, green landscape they give at first a most agreeable impression. All were founded in the course of the general penetration of the region by whites and half-breeds from the neighboring areas. Cuevo, among the above-mentioned, is of most recent origin, an outpost of the last half of the past century placed in the extensive valley which formed then the last stronghold of the free Chiriguanos.

The ground plan of these urban settlements is always that of the typical Spanish colonial town with rectangular streets and a central plaza. The houses are better constructed than those of the Indians, the walls are of adobe and the roofs are covered with tiles. The house

type shows immediately the origin of the first white settlers. The northern urban settlements such as Cuevo, Monte Agudo, and Lagunillas, which were founded by Santa Cruzeños, have also the typical house form of the Santa Cruz region with a veranda on the front. As every house has such a veranda, there runs along the streets a continuous corridor shading the sidewalk (pl. 23*b*). Entre Rios, founded from Tarija, lacks this typical veranda. The general impression one gets of such a little town in the East Bolivian ranges is that of absolute stagnation. One hundred fifty to two hundred houses form the settlement, the inhabitants of which dedicate themselves only to trade in the smallest form. They live quite isolated from the rest of the world, with which not even a road connects them.

Local names.—These urban settlements were named by the Spaniards, but although they are fairly recent several of them have since changed their names. In the East Bolivian ranges, as well as elsewhere, local names disclose the chief preoccupations of those who formed them. The modern Bolivian is interested most of all in politics and the names of the prominent public men appear conspicuously in the local denominations. The former town of Sauces is now called after the national hero Monte Agudo, and even a saint was replaced by a former president of the Bolivian republic, the village of San Francisco on the bank of the Pilcomayo now being called Villa Montes. Such rebaptism is likely to confuse the cartographer; for instance, in the 1925 edition of Stieler, Villa Montes–San Francisco is shown as two distinct towns!

Quite different are the local names of the Chiriguanos. The names they chose show that all their thinking centered actively around certain features of the natural landscape which were of practical importance for them. A torrential river, the bed of which lacks firm ground because of its dangerous character becomes therefore Parapiti (murderer water). Another stream which provides them with the good fishes is the Pira-i (fish water). Where rivers break through the ranges they often form rapids so that fish can ascend only by leaping through the rapids. Such a place is called then a Pira-po (fish-jump). Tarei-iri is a place where the tarei, a fish, is common. On the border of the poorly watered Gran Chaco the presence of water is of highest importance for the Indians. Ita-tiqui (stone which drips) is the name of a small Indian village of unconverted Indians situated on a poor spring east of the Sierra de Aguaragüe. Even to the east of this range within the Chaco proper, a low, small anticline of the Puca formation

appears, and whereas all the region around has only miserable, small waterholes, good springs issue here from the rocks. This place is Ñanca-roinza (spring of fresh water). Also the bad smell of the sulphur springs attracted their attention. Ingre (stinking water) thus got its name.

The wild fruits of the forest also play an important part in the life of the Chiriguanos, especially when the corn harvest is insufficient. The names of the trees and plants which provide them with food at such times are therefore often given to settlements. Aguairenda is the place where the aguai (*Styrax*) grows, a large tree with a fig-like fruit. Another place is called simply Aguai. Murucuyali, Machareti, Iguembe, are other Indian settlements which got their names from different wild fruits of the forest. Also the reed (*tacua*) which they employ in the building of their houses appears in local names as *tacua-renda* (reed place) or *tacua-r-i* (reed water). Carandaiti has been named after the palm trees in the neighborhood.

Wild fruits, fish, water, and structural materials are the items of most importance in the landscape for the Chiriguanos and the names of these objects appear everywhere in their local names. This simple nomenclature became in the course of time, however, more complicated. When the Spaniards introduced the first domestic animals these attracted the attention of the Indians. A place where a white man lived who owned cattle or dedicated himself to cattle-breeding became for them Huaca-ia; *huaca* corrupted from the Spanish *vaca* (cow) and *ia* (the proprietor). Huaca-reta (plural of cow) is another place, the name of which is derived from cow.

These simple but significant names did not please the Italian missionaries of the Franciscan Order. Because Chiriguanos were very attached to them, they made a combination and added the name of a saint to every Chiriguano place where they founded a mission. Rosario del Ingre, San Antonio del Parapiti, San Buenaventura de Ivu-und, and San Pascual de Boicovo are instances of such combined local names that disclose the abyss which separates the mentality of the Chiriguano from that of his Christian missionary, a cultural gulf which even the Franciscans admit, has been bridged only in exceptional cases.

The distribution of local names of Guaraní origin still coincides with the habitat of the Chiriguanos. They do not pass the limits of the East Bolivian front ranges with the one exception of those already mentioned who are situated along rivers in the western border of the

Gran Chaco. Their former distribution, however, may have extended farther south into the arid northwest of the Argentine, where typical Guaraní sepultures—the bodies buried in urns—have been found.[66]

The Economic Life

The natural resources of the landscape form, of course, the basis of the economic life of the East Bolivian front ranges. Its difficult accessibility, the consequence of which is an extreme isolation from the neighboring areas, also has great influence. The mental orientation of the inhabitants is at least as important as the physical environment. The economic development of the landscape has taken quite a different course from that which might be expected of a more active racial stock of European origin. Though acquainted with the environment we must still try to understand at least the chief features of the economic attitude of the inhabitant in order to understand the manner in which he actually gets his living out of the area.

Native economy.—The original economic orientation of the native population—the Chiriguànos—differed largely from that of their neighbors in the west and in the east. The Chaco Indians were chiefly nomadic—hunters and collectors of wild fruits. Nature provided them with every want. The highland dwellers, on the contrary, lived in an environment which voluntarily gave them almost nothing; they lived exclusively upon the produce of agriculture and the breeding of llamas. The Chiriguanos between them were intermediate also as to the problem of subsistence. They exploited nature directly as fishermen, hunters, and collectors of wild fruits, but they cultivated always some small fields, especially of Indian corn. They were neither nomads like the Chaco Indians, nor did their agriculture develop to the degree it did among the highland Indians. The agricultural methods of the Chiriguanos remained in the most primitive state. Nowhere did they use the water of the many streams for irrigation, although by so doing they would not only have augmented the cultivable surface, but they would also have become independent of the irregular rainfall and could have increased the number of crops to at least two each year. They cleared their fields by fire and did not even know the wooden plow of the Quichuas for their cultivation; they used for this purpose nothing but a wooden hoe (*Hackbau*). Thus

[66] Eric Bowman, Antiquités de la région andine de la Rép. Argentine et du désert d'Atacama, vol. 1, pp. 255–279 (Paris, 1908).

they prepared after the first rainfall in November their little fields. Three months later the crop began to provide them with their chief food and their preferred drink, *changui,* a maize beer. The importance of corn as food is shown by the variety of its preparation: the Chiriguanos had twelve different names for differently prepared corn.

Maize, cultivated in the most primitive form, was thus the chief basis of livelihood of these forest Indians. Nature provided them liberally with the rest of their wants, especially with fish, the meat of wild animals, and with wild fruits. The most important among the latter is the algarobo tree. They eat its fruit and brew with it another common beer. A large number of other wild trees and plants such as the mistol, chañar, aguai, guembe, murucuya, etc., provide them with fruits when the drought destroys their crops. This primitive economic system enabled a certain harmony between the nature of the landscape on the one hand, and the restricted capacity of the natives to make use of their land on the other. A tribe of some two hundred thousand Indians could maintain itself permanently in this region under such an economic system.

European influence.—A change took place when whites and half-breeds of the neighboring landscapes penetrated into the forests of the Chiriguanos. Their economic influence was chiefly of two kinds: First, they introduced domestic animals, especially horses, mules, donkeys, cattle, goats, sheep, and pigs. The corrupted Spanish names which the Chiriguanos use for these animals prove their origin. Only for chicken and dog do the Indians use Guaraní names; a fact which does not prove that they possessed these animals originally but rather suggests that they were introduced by inter-tribal trade from the Brazilian coast more rapidly than the Spaniards advanced.[67] The whites introduced not only domestic animals into the region, they also improved agricultural methods. The plow and the iron spade were introduced and are now in general use. Also the number of cultivated plants was augmented.

One might believe that these innovations would have had in general a favorable influence upon the economic life in the East Bolivian front ranges. The contrary however took place. The new ethnic element brought with it no intention to dedicate its physical energies to real productive work. The missionaries alone used at least their mental superiority in a manner that they believed was of

[67] E. v. Nordenskjöld, Comparative ethnographical studies. Vol. 5: Deductions suggested by the geographical distribution of some post-Columbian words used by the Indians of South America (Goteborg, 1922).

benefit to the Indians. The accumulation of reserves of corn in the missions against times of drought proved as useful to the Indians as did the protection which the missionaries gave them against exploitation by the other whites. The Chiriguanos themselves recognized these advantages and it was only because of this economical viewpoint that they admitted the missionaries voluntarily among themselves.

The number of the missionaries, however, was very small compared with the increasing number of other whites and half-breeds that penetrated into the area with the sole intention of imposing themselves as a dominant social group, thus exploiting the original inhabitants. The whites maintained their economic dominance quite brutally at the expense of the Chiriguanos. Since, however, the Indian would not adapt himself to this new state of things by working more and living worse for the benefit of the intruder, the former economic harmony became dangerously disturbed. The Chiriguano tried to elude the increase of labor as well as he could: first by rebelling from time to time, and when that failed by emigrating or by race suicide. Nobody can foretell the final result of this economic and social development.

Actual economic status.—The most important product of the area is today, as it was formerly, Indian corn (fig. 10). The total production, however, is not greater than the consumption by the population; there is no surplus to be exported. The surface under cultivation is extremely small compared with the total extent of the area and it seems to be decreasing rather than augmenting. I saw new fields recently cleared from the forests, but on the other hand, numerous settlements such as Chimeo, situated in a charming place with abundant running water for irrigation, that once were flourishing but where now not only the fields but even the houses are invaded again by the forest (pl. 23*a*). In the last decades the cultural landscape has degenerated greatly.

Besides maize, every Chiriguano plants different kinds of calabashes which he uses partly as food but also for the manufacture of bowls and bottles, the form varying with the kind of calabash. Beans, sweet potatoes, and melons are also frequently cultivated, but sugarcane, manico, peanuts, tobacco, and fruit trees are rather rare. The moist climate seems not to be suitable to the vine; wine is imported from the more arid valleys of the eastern Puna, especially from Tarija and Camargo.

Of the imported domestic animals the pig adapted itself best to the rainy forests of the East Bolivian ranges, wild fruits furnishing abundant food and water being easy to find. Pork is, however, essentially a product for local consumption only. The export of live hogs takes place but finds a market only in the mining districts of the high Puna where the hog fails to reproduce and where there is a denser population of somewhat superior purchasing power. The distance from the rainy forests of the east to the mining districts of the high Puna is more than two hundred kilometers in an air line, and they can be driven only in small herds to their destination. I saw such droves from the region east of Monte Agudo on the way to Potosí. With every twenty to twenty-five pigs goes an Indian drover. The hogs need as an average three months to get to their destination. Export under such difficult conditions is of course only possible because the pigs were raised in the forest without expense and especially because the labor and keep of the Indian drover is extremely cheap.

Cattle-breeding is most important along the Chaco border and in the interior plains between the East Bolivian ranges, where arid forests form extensive natural grazing grounds and where wild fruits such as that of the algarobo give a substantial fodder. However, in dry years or when the rainy season is delayed there is a shortage of cattle feed in these places and a lack of water. In such years many hundreds of cattle perish from hunger or thirst. Since the cattle live in a nearly wild state "in the bush" and are rounded up only in order to sell them, there is no possibility of a fair estimate of the total stock. In a particularly well administered estancia on the Pilcomayo it was thought that there might be at the time ten thousand head of cattle, but that possibly there were no more than six thousand.

Although stock ranges along the eastern border of the Andes in large numbers, and the breed is strong and big (pl. 25*b*), the economic value of the livestock is actually small. The needs of the population are easily satisfied as everybody eats his fill of *charqui,* air-dried meat, and prepares his own supply. On the other hand, there exists no possible way of exporting the abundant surplus in any direction. To the east is the wild Chaco, the inhabitants whereof levy on the local supply by means of theft. To the west are situated small cities, such as Sucre, Tarija, and Padilla, with a very restricted capacity. In any one of them the arrival of a small herd of cattle brings down the meat prices immediately. The mining districts of the Puna, where there is

a continual demand for meat, are very far. Herds en route to the mines must first cross the East Bolivian front ranges with their terrible trails and dangerous plants, such as the romerillo, which the animals of the Chaco do not know. When the forests of the east have been passed there still remains a long way across the Puna, a route that is economically difficult since fodder on the Puna is always limited and mostly very expensive. Under such conditions the Chaco cattle cannot compete in the Bolivian mines with the cheap and good Argentine meat which comes directly from the south.

Until a few years ago there remained at least one possibility: the cattle were driven through northern Argentine via Salta to the nitrate fields of northern Chile. Some years ago the Argentine Republic prohibited the import and passage of Bolivian cattle, thus depriving the Bolivian Chaco and parts of the East Bolivian front ranges of the only really paying basis of sustenance.

The only mineral product of the area to date is salt, found in small beds in the south of the region near Entre Rios and Salinas. It is there exploited in a primitive way and provides the entire region as far north as Santa Cruz de la Sierra. The salt of the more distant Salinas of the Puna cannot compete here. As far west as Tarija one can see the reddish salt of the Puca formation in the shops. At this place one also encounters the gray salt of the Salinas of the Puna.

Such are the chief economic features of the association in the East Bolivian front ranges of Chiriguano, white and halfbreed. But to these chief ethnic elements were added in the last decades others of different stock, numerically without importance. Among them are the so-called "Turcos." They are not national Turks but mostly Syrians or Armenians who dedicate themselves exclusively to trade on a small scale. As merchants they are far superior to the Bolivians. They advance into the most isolated Indian villages as well as into the greater towns. In the small Chiriguano settlements the Turco is the king of the merchants. The difficult struggle for life in his native country is here resolved into an easy pastime. It is astonishing how he is able to make money in a locality where none is apparent. As a pitiless exploiter of the Indian, the Turco is perhaps without a match.

In Villa Montes a German firm has owned a large estancia since about 1910. The original plan had been to irrigate the land with the water of the Pilcomayo and to settle the extensive estate with Germans, but the outbreak of the war made the realization of this experiment impossible. It also soon turned out that the installation of an irri-

gation system would have been impracticable. Cattle-raising remained therefore the only possibility. Even on this basis the place yielded good returns for several years until the Argentine border was closed for Bolivian cattle. A similar enterprise made by North Americans somewhat farther south failed and the settlers left the colony with their families. Such experiments prove only that under existing economic and social conditions the colonizer, even of the most energetic stock, is condemned to fail, as he is isolated among an indifferent population, finds no coöperation, and has as his prospect a gradual reduction to the social position of the Chiriguano: an object of exploitation.

Far better are the chances for an economic rejuvenation since a big capitalistic group, with abundant means to overcome any difficulty which might arise either from isolation or from the inertia of its inhabitants, has become interested in the mineral resources of the area. The Puca formation was called some forty-five years ago the *formación petrolífera*. Only recently has the serious exploration of this formation begun. A few years ago the Standard Oil Company obtained a large grant which covers practically the whole of the East Bolivian front ranges. After preliminary topographic and geologic exploration wells were sunk along the Chaco border. Caravans of carts brought the material from the Argentine railroad north by the Santa Cruz road. The first test-well, near Fortín Campero on the Argentine border, was successful, oil being found in three different horizons. Another well farther north near Saipuru struck oil at a depth of one hundred and fifty meters. Two others had to be abandoned without result at nearly six hundred meters. At the beginning of 1925 two wells were being sunk at Ñancaroinza and Charagua. Upon the results of these explorations depends largely the possibility of an economic change in the life of the East Bolivian front ranges.

Communications in the East Bolivian Front Ranges

The network of highways (fig. 11) is still very undeveloped in the East Bolivian front ranges. In the whole area there is not a single road for wheeled traffic. In a north and south direction along the strike of the ranges rivers oppose the only obstacles to the traffic, but these are not to be disregarded, especially during the summer. When I came to Monte Agudo from the south through the meridional valley of the Rio Sauces by the *camino nacional* we crossed the meandering

course of this river thirty-three times in one day. It being the rainy period every crossing was dangerous and to miss the ford in the turbulent water was an uncomfortable and decidedly nerve-racking experience. The reason why there are no better routes in a north–south direction is that there is only a limited need for communication in this particular direction. The meridional structural valleys are areas of uniform production and need no exchange of goods among themselves. The necessity of communication is greater in a west–east direction because the Chaco in the east and the Puna in the west are regions which differ markedly in their production from the East Bolivian front ranges. Nature opposes strong resistance to any traffic along this line. Traveling from Tarija to the Gran Chaco one has to cross about fourteen greater ranges which are as a rule steep, sandstone hogbacks. The rivers break through these ranges but always in such narrow gorges that they are impassable for the traveler (pl. 20*a*). These natural obstacles are so great that from the Rio Grande in the north to the Argentine frontier in the south, a distance of nearly four hundred kilometers, there exist only two or three west–east trails which cross the East Bolivian ranges in their entire breadth, connecting thus Chaco and Puna. The principal ones are from Monte Tarija by way of Entre Rios to the Chaco and the other from Padilla via Monte Agudo to the Chaco. These miserable trails carry the high-flown name of *caminos nacionales* as the national government is supposed to keep them in good order. Even these trails are in part so steep or in such bad condition that they are impassable for a normally loaded pack animal. The argillaceous sandstone becomes very slippery, especially after the heavy rainfalls of summer. Whoever wants to travel on these trails must not only load his pack mules lightly, he must also take with him enough spare animals to make good almost certain losses.

I started from La Quiaca to Villa Montes with two saddle mules and one pack mule. All three were strong animals in good condition, but none of them lasted through the journey. One ate romerillo and was dead the next morning, another fell down a precipice, and the third became so feeble that it was impossible to go on using it. I was thus obliged to buy new mules on the way in order to keep my caravan going. Even that is always expensive as natives take advantage of the situation of the traveler and charge him prices which are twice and even three times the normal ones. Fortunately our cargo was of small weight, not more than 60 kilograms. A good mule on

the Puna or in the Chaco may easily be burdened with 150 kilograms. With our small burden we could pass even over the steepest parts of the trails. Where it was necessary I shouldered half of the baggage and marched ahead, behind came the unloaded mules, and at the end the muleteer with the other half of the burden.

If one leaves the two *caminos nacionales*, the situation is still worse. The trails are mostly used by Indians afoot and are as a rule so narrow that persons can pass only in single file. A loaded mule may run its pack against a tree at any moment with a halt and rearrangement of the pack always as the consequence. Some trails follow the bed of a creek. When it does not rain and the river has no water it is often quite agreeable to travel along such a shady bed. But when it begins to rain and the water rises suddenly there remains no other alternative than to leave the bed of the creek and penetrate into the wet, dense forest, to wait there until the water recedes again. To pass a night in the forest, soaked to the skin without even space to pitch a tent is one of the likely inconveniences of traveling in the East Bolivian ranges wherever one abandons the main trails.

To these difficulties are to be added the river floods which in summer often detain the traveler for weeks. There are many rivers in the East Bolivian front ridges and along the Chaco border, but not a single bridge. On the Pilcomayo there is one small ferry-boat which carries people from Villa Montes across the river. Otherwise one is always obliged to ford the rivers. As the height of the water is always, and often rapidly, changing, one must hazard the guess whether the ford is still passable or not, principally by noting the color of the water.

The choice of a season for traveling is not without its difficulties. In summer during the rainy season one has always abundant feed for the mules but the rivers are high and dangerous. The heavy rains soak the saddles and it is almost impossible to avoid having saddle-galled animals. In winter there is no difficulty with rivers and no trouble with rain, but it becomes often nearly impossible to get feed, especially when the dry season is abnormally long and the reserves are exhausted.

The first trip from west to east across the East Bolivian front ranges was made under the most unfavorable conditions. The dry season of 1924 lasted exceptionally long. At the start in Tarija in December the first rains were just beginning. Good pasture grounds were not found until we got to the Chaco. Before then we suffered

from the consequences of the dry season as much as from the beginning of the rains. The high rivers made difficulties, the wet saddles caused sore animals, and there was still shortage of fodder. The best period to travel, without doubt, is the end of the rainy season, normally in May. The advantages of the rainy season are then for a while combined with those of the dry period; one still finds good grazing grounds everywhere and the rivers are steadily falling. The end of the rainy season, however, is subject to considerable variation and even the most circumspect traveler may experience disagreeable surprises.

Under such difficult conditions it is natural that traffic in the East Bolivian ranges is insignificant, as everybody realizes who travels even on the main trails. Whoever is not absolutely obliged to cross this area avoids it. As a rule travelers from the Bolivian high plains to the Chaco take the route via Jujuy in the Argentine and from there along the Chaco border to Tartagal, the final station of the Argentine railroad in 1925. From there one travels with mules or horses through the flat Chaco northward. On the main trails through the forest-covered ranges one rarely meets a traveler other than the natives. When the main trails are left behind one can ride for days without seeing a human being or a settlement.

The Material and Mental Culture of the Inhabitants

Material culture of the natives.—The house of the Chiriguano has been described as spacious, lofty, and always pretty clean. The furniture is primitive but never wanting. The Chiriguano sleeps at home on a bed made of reeds covered with hides. The hammock, which is in general use in the Santa Cruz region is not found south of the Rio Grande, the nights being often rather too cold. A small bench is never wanting.

Bowls and plates for daily use are still mostly homemade, either calabashes fashioned by the men, or pottery made by the women. In pottery, as well as in other home manufactures, the Chiriguanos certainly learned much from their western neighbors on the high plains. But in general their original household industries give way rather quickly to cheap imported material. Hand woven clothes of cotton or wool, for instance, have been largely replaced by imported materials.

The chief clothing of the women is a sacklike gown without sleeves called *tipoi* (pl. 25*a*), fastened by a silver pin like that of the

Quichua Indians. Many of them, however, have adopted clothes of European style, especially through the influence of the missionaries. The men, nearly without exception, wear European dress, but still use a poncho like that of the highland Indians. Their old holiday dress consisting of a coat and trousers of tanned leather is now out of use, except for gauchos who have adopted it partly. These combine the *coleto* or leather coat with the *guardamontes,* fixed to the saddle to protect the legs when following cattle in the thorny Chaco monte.[68]

The *tembeta* (*tembe,* underlip; *ita,* stone), a round piece of wood or now mostly an imported button of tin, introduced in a perforation of the underlip, was once the general mark of distinction for a male Chiriguano. Only the unconverted Indians of the older generations still use the tembeta. The old Chiriguano custom to adorn the face with red paint, made from the seed of the *urucu* (*Bixa orellana*), is still to be found even among the Christian Indians.

Very pleasing is the cleanliness which distinguishes the Chiriguanos from all the highland Indians and from most of the Chaco Indians as well. Every day begins with a bath and even in places where the water is scarce one sees them squatted around a waterhole pouring the water over each other with little calabash bowls. When the water is muddy they clean it by agitating it with the juice of certain plants (pl. 25*a*). These bathing customs, striking especially where they are maintained in opposition to the influence of the environment, are derived perhaps from the time when they lived on the banks of the upper Paraguay where water was always abundant.

In general, the original material culture of the Chiriguanos is being rapidly displaced by the imported European civilization. The inferior tribes of the Chaco like to imitate the higher culture of the Chiriguano, adopting the tembeta for instance, as did the Tapiete. The Chiriguano has never adorned himself with feathers as the Chaco Indians do; his aspiration is to acquire a hat and to become equal in his clothing to the white or mestizo. He distinguishes himself in this respect from the highland Indian who is much more convinced of the high value of his own traditional culture and lives therefore mostly far better content with his fate and culture than does the Chiriguano.

Mental culture of the Chiriguano.—Nearly as rapid as the material culture is the loss of the original mental culture of the Chiriguano. His language is still spoken everywhere in the East Bolivian front

[68] E. v. Nordenskjöld, Indianerleben, *op. cit.* B. de Nino, Ethnografía Chiriguana, *op. cit.*

ranges and even among the Chaco Indians is the "diplomatic language." But the Guaraní is being rapidly corrupted, giving way more and more to the Spanish language which they learn by contact with whites and cholos and which the missionaries teach them. The Spanish language is almost the only beneficent item of mental culture which these immigrants brought to the Chiriguano. The missionaries who taught them the Spanish language and also Christianity, have had only a formal success. Some of the missionaries confess that there is nothing to be found among the Chiriguanos that might be considered a real Christian faith or even dogma. Scarcely one Chiriguano in good health will allow himself to be converted, except for some economic reason. The younger generation takes as little interest in the Christian religion as in the old myths of their tribe.

The Chiriguano prefers idleness to anything else. During the day one usually sees the men sitting around or lying on their beds. Their interest centers upon women and *cangui*, corn, or algarobo beer. The latter is more and more supplanted by imported liquor. The effect is noted in the character of their fiestas, which often have a sanguinary end. Even the fiestas themselves have changed and the carnival, imported by the whites, is now the *arete*, the fiesta par excellence. The character of the Chiriguano wants absolutely the conservative trait which characterizes the highland Indian; on the contrary, adaptability, combined with inconstancy, is one of his chief features. The formation of a class of halfbreeds goes on steadily.

The mental culture of the immigrated whites and cholos is not even on as high a level as that of the similar class which we know from the eastern Puna. They do not at all maintain an isolated higher culture but are culturally strongly declining towards the Indian state. It has happened during a smallpox epidemic that the whites have asked a Chiriguano medicine man to protect them, instead of vaccinating themselves. The absolute isolation in which they live favors strongly the tendency toward cultural decline.

CONCLUSION

Not only are the features of the two landscapes, the eastern Puna and the front ranges of the East Bolivian Andes essentially different, but also human life has developed in each in quite a different way. The dwellers of the Puna and its valleys have the older culture but the population of this area has passed the climax of its development. No improvement of their economic life has taken place since the Spanish conquered the high plains. There is no indication that the land might attract in an early future a greater number of foreigners who would be capable of improving by means of greater energy the economic methods hitherto used by the native population. The highland Indian does poor work but he does it so cheaply that he is still the best rural worker for the landed proprietor. The high prices of land must deter prospective settlers. This condition itself arises from the fact that only the highland Indian, blindly attached to the soil of his ancestors, will pay the uttermost in rentals, not worrying about the actual return of his little farm and scarcely considering the chance of bettering himself away from his ancestral home.

The history of man in the front ranges has been quite different and so is likely to be its future development. The forests of the east were settled later than the Puna and probably later also than the Chaco border. The migrations which brought Guaraní Indians from the upper Paraguay to the eastern front ranges of the Bolivian Andes lasted into the sixteenth century. If the newcomers found there other tribes, these cannot have been very numerous, for no remainder of them has been found. It was only several decades ago that the eastern forest was opened to and conquered by European civilization, such as it is. The contact with it has brought to the Chiriguanos until now nothing but its disadvantages. The area is being depopulated continually. This may be only a transitory phenomenon. Perhaps in the near future the oil industry will give a new impulse to the economic life in the landscape and will give better working conditions to its inhabitants. Perhaps, too, such expectations will soon be given over and the future development will be retarded. However, in the end no extensive and fertile landscape of the earth such as this is will lie fallow, even when it is in a most isolated location. The front ranges of the East Bolivian Andes form one of the economic reserves of South America.

EXPLANATION OF PLATES

PLATE 3

a. The Puna proper; an undissected high plain. Road from La Quiaca to Tupiza.

b. The Puna plain east of La Quiaca covered with tola heath. In the background the Cordillera de Santa Victoria, a normal Puna range. February, 1925.

a

b

PLATE 4

a. Looking south from the Abra de Chorcoya over the Pampa de Tacsara and the undrained Lagunas de Patancas.

b. The southern part of the Pampa de Tacsara dissected by the affluents of the Rio San Juan del Oro (see fig. 1). The young Puna fill forms steep barrancas.

a

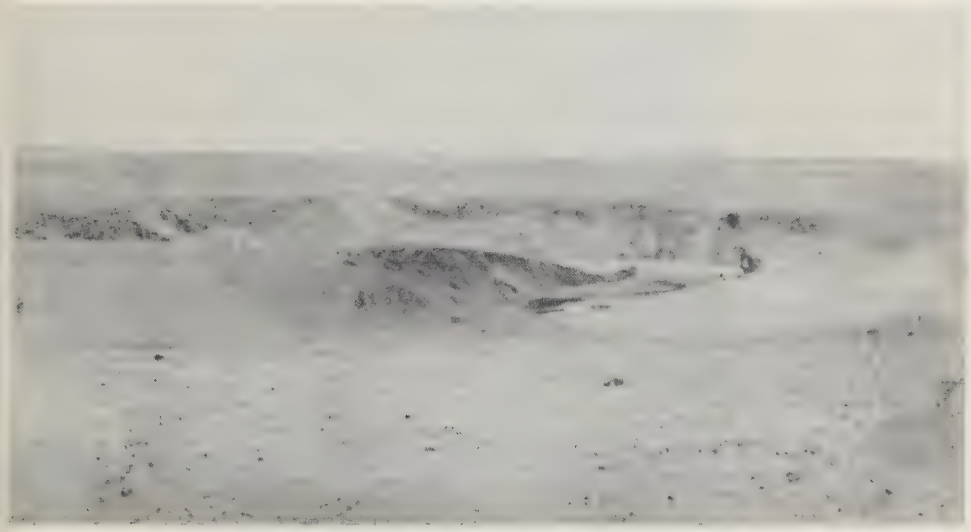
b

PLATE 5

a. Sansana, a high Puna settlement without nucleus, consisting of isolated dwellings scattered in a dale from which one of the affluents of the Pilcomayo rises. The creek has cut its bed into the Puna peneplain (foreground at the right); the white outcrops are recent volcanic ash.

b. The incision of one of the affluents of the Pilcomayo in the Puna peneplain near La Quiaca. Outcrops of folded Silurian schists on the slopes.

a



b

PLATE 6

View from Mojos, situated between La Quiaca and Tupiza, toward the north. In the west the undissected Puna; from the east the affluents of the Pilcomayo cut deep erosion valleys in the Puna peneplain.

PLATE 7

The Rio San Juan del Oro occupies but a small fraction of its bed in winter. The valley is over large distances so narrow that there exists nothing like a valley floor; the slopes consist of Paleozoic schists; along them runs the high-water trail used during the rainy season.

PLATE 8

a. The synclinal valley of the Rio San Juan del Oro.

b. A paved dike-like road in the ruin Antigal de Alisos.

E.
S.
W.
Puca Sandstone
Silian
under talus
Puca Sandstone
Rio San Juan del Oro

a

b

PLATE 9

a. Palqui, a ruin east of the Rio San Juan del Oro, now invaded by a cardonal.

b. Ruins of dwellings in the Inca fort, Condor Huasi.

a

b

PLATE 10

a. Highland Indians living in a round hut (*Palqui viejo*); the only dwelling of this type observed during the journey. These huts were formerly much in use among the Puna dwellers; e.g., ruins of Casabindo, northwest Argentine.

b. Type of dwelling in the valley of Vitiche, eastern Puna. The house is roofed with slabs of Paleozoic schists.

a

b

PLATE 11

a. Isolated dwellings of stock-raising highland Indians in the eastern Puna. Vegetation: tola heath and chandelier cactus.

b. La Quiaca, on the Puna plain.

a

b

PLATE 12

a. Llanta Apacheta (Millares); Indian settlement in the valley of the Rio Matacas.

b. Street in Yamparaez, one of the larger Indian settlements between Sucre and Padilla.

a

b

PLATE 13

a. A street in Sucre.

b. View from the Iglesia Matriz across the town; the Cerro Potosí.

a

b

PLATE 14

a. A street in Potosí; all the houses are built in the typical Spanish colonial style, most of them two-storied with balconies.

b. The market of Potosí.

a

b

PLATE 15

a. Unirrigated fields on the mountain slopes. Road from Soudáñez to Tarabuco. The major part of the surface is fallow land.

b. In the valley of the Rio San Juan del Oro. A settlement stands on the slope and the river bed is planted with wheat.

a

b

PLATE 16

a. The primitive wooden plow which is still in general use among the Puna Indians.

b. Vehicles are seldom seen outside the greater urban settlements of the eastern Puna. This is one of a primitive type such as is used in the valley of the Rio San Juan del Oro.

a

b

PLATE 17

a. A typical Indian caravan. Every Indian drives a single beast of burden. Their leather helmets (*montera*) characterize the Indians of the Sucre region.

b. Llama herd from the western Puna in the valley of the Rio San Juan del Oro.

a

b

PLATE 18

a. On the automobile road from Sucre to Potosí after a rainfall.

b. Isoclinal valley in the Front Ranges. The dip slopes of the Sierra de Mandiyuti at the right.

a

b

PLATE 19

View from the range west of Monte Agudo over the western ranges of the East Bolivian Andes.

PLATE 20

a. The Pirapo of the Pilcomayo in the Sierra de Aguaragüe west of Villa Montes.

b. Moist mountain forest east of Narvaez.

a

b

PLATE 21

a. Coniferous forest on the range west of Narvaez.

b. Xerophytic bush steppe in the depression of Chimeo. The vegetation in this inter-Andean valley is the same as in the Chaco. At the left of the rider the characteristic "palo borracho."

a

b

PLATE 22

a. Scrub steppe of the Chaco south of Boyuibe. Photograph taken December 31, 1924. At this time the Chaco is normally green under the influence of the first rains.

b. The mission settlement of Machareti seen from the mission building. In the background the Sierra de Aguargüe.

a

b

PLATE 23

a. The decayed church of Chimeo, a former Franciscan mission now invaded by forest.

b. A street in Cuevo. The houses are of the Santa Cruz type, one-storied and with gallery in front.

a

b

PLATE 24

a. Former mission settlement San Antonio on the south bank of the Pilcomayo. Toba Indian and Indian dwellings.

b. Corn graneries of the Chiriguano type in Choretimi, between Cuevo and Monte Agudo.

a

b

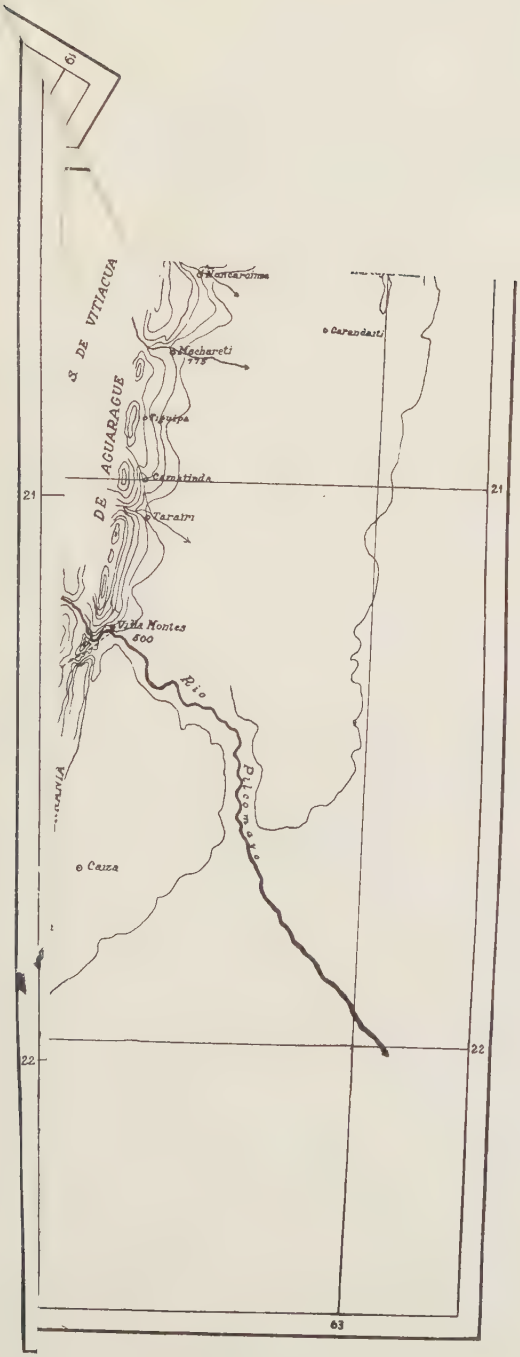
PLATE 25

a. Chiriguano woman cleaning the turbid water of the Pilcomayo with vegetable juices.

b. Chaco cattle at Villa Montes, the Serranía de Aguaragüe in the background.

a

b


S. DE VITIACUA
DE AGUARAGUE
Nancaroima
Carandaiti
Mechareti
775
Tipuipa
Camatinda
Tarairi
Villa Montes
500
Rio
Pilcomayo
Caiza
21
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63

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THE CYLINDRICAL EQUAL-AREA PROJECTION FOR A NEW MAP OF EURASIA AND AFRICA

BY

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TYPES

The normal type of cylindrical equal-area projection is simple, easily understood, and easily constructed (fig. 1). The meridians are straight lines, parallel and equidistant; the parallels of latitude are also parallel straight lines but the intervals between them become progressively less toward the poles (fig. 2). In this projection areas are represented truly and form is good near the equator, but violent distortion of form is produced near the poles. Because of this distortion the projection is ordinarily considered to be of very little importance.[1]

The true utility of the cylindrical equal-area projection can be appreciated only when the more generalized forms are considered. The normal or equatorial type is developed from a cylinder tangent at the equator. The transverse members of this family of projections may have their circles of tangency on any great circle (fig. 8). In the simple equatorial projection the cylinder axis coincides with the axis of the sphere. In the transverse projection, in which the cylinder axis is at right angles to the axis of the sphere, the circle of tangency is on a meridian of longitude and is here called the meridional cylindrical equal-area projection (fig. 3). The transverse type, in which the circle of tangency cuts the equator at an angle of less than 90°, is in this paper called the oblique cylindrical equal-area projection (fig. 4).

[1] "This projection is one that is of very little use for the construction of a map of the world, although near the equator it gives a fairly good representation. We shall use it mainly for the purpose of illustrating the modifications that can be introduced into the cylindrical projections to gain certain desirable features." —Deetz, C. H., and Adams, C. S., Elements of Map Projection. U. S. Coast and Geodetic Surv., Spec. Publ. 68, p. 30.

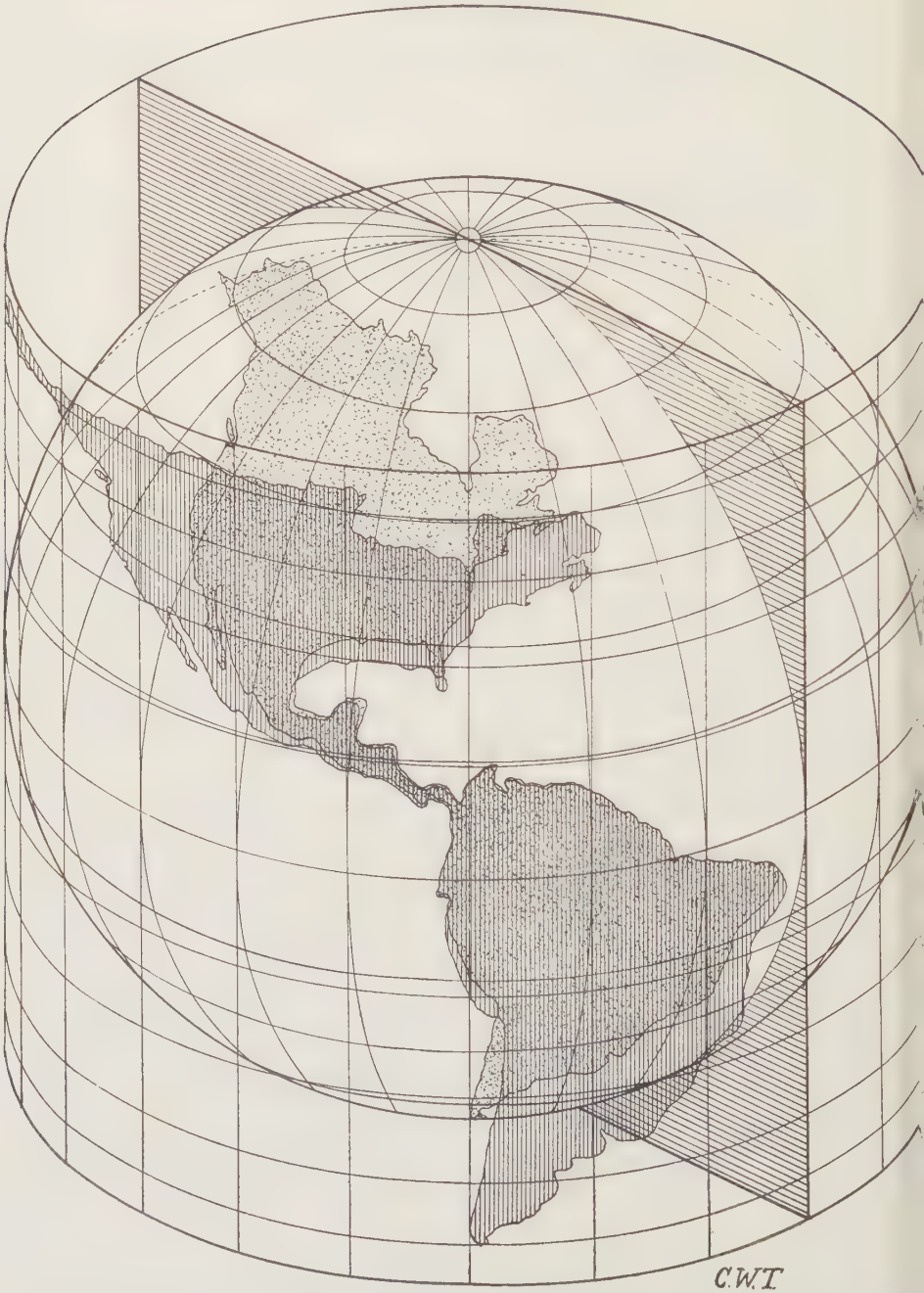

Fig. 1—Diagram showing equatorial development of the cylindrical equal-area projection

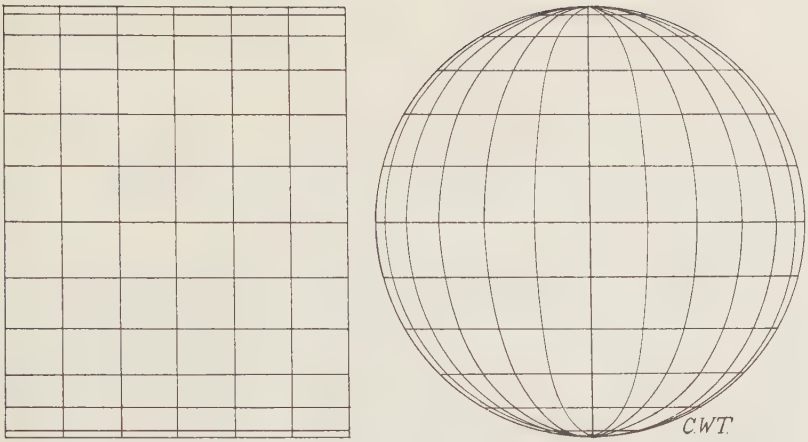

Fig. 2.—Geometric development of equatorial cylindrical equal-area projection.

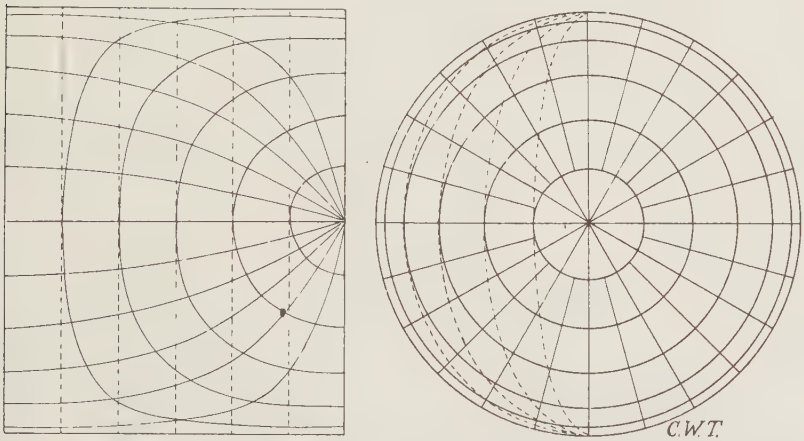

Fig. 3.—Geometric development of meridional cylindrical equal-area projection.

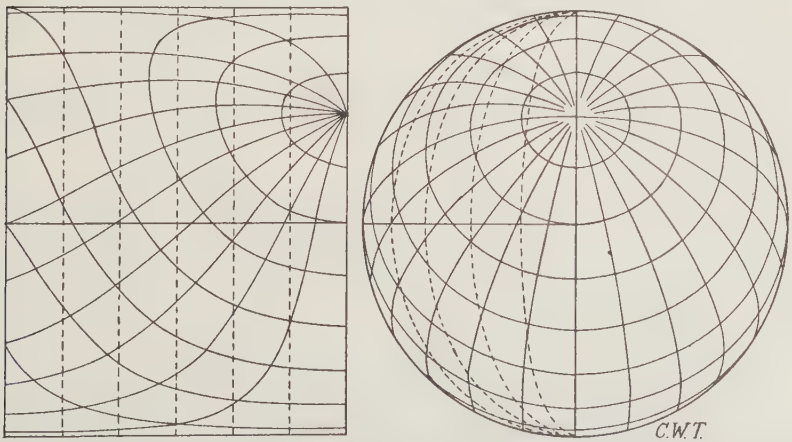

Fig. 4.—Geometric development of oblique cylindrical equal-area projection. Circle of tangency of the cylinder cuts the equator of the sphere at an angle of 60°.

TRANSVERSE PROJECTIONS HISTORICALLY CONSIDERED

The transverse cylindrical equal-area projection has been utilized to some extent in Continental Europe. In 1772 Lambert[2] published a treatise containing a map in which the circle of tangency of the cylinder followed a meridian. He also developed the formulae required for its construction. Tissot,[3] in 1881, considered transverse cylindrical projections. The discussion includes the Mercator, the equal-spaced (*quadratische Plattkarte*), and the equal-area cylindrical projections, but it considers only the special case in which the circle of tangency is a meridian. The formulae for conversion of coordinates are developed, which for the equal-area projection are those of Lambert. Hammer[4] in particular has given attention to this projection, outlining in some detail the employment of transverse (*nicht-normale*) cylindrical projections. He suggests specifically the usefulness of the meridional cylindrical projection for South America, in which the circle of tangency is the meridian of 60° W of Greenwich. He also suggests two uses of the oblique type: (1) to show the New World, the great circle of tangency extending from Alaska to Patagonia, and cutting the equator at about 65° W longitude, (2) to show the British colonial realm in Asia and Australia on a cylinder tangent along a great circle passing from the British Isles through India, the Malay Archipelago, New Guinea, and Australia to New Zealand.

In 1904 Hammer[5] suggested two practical examples of the use of the oblique cylindrical equal-area projection. He applied it to the representation of areas adjacent to two selected great circles. These examples are practically the same as those published in his *Kartenprojektionen* fifteen years earlier.

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[2] Lambert, J. H., Beiträge zum Gebrauche der Mathematik und deren Anwendung, 1772, Teil 3, pp. 180 ff. Reprinted in Ostwalds Klassiker der exakten Wissenschaften, no. 45.

[3] Tissot, A., Mémoire sur la représentation des surfaces et les projections des cartes géographiques (1881), p. 160; issued in a German edition by Hammer, E., Die Netzentwürfe geogr. Karten nebst Aufgaben über Abbildung beliebiger Flächen aufeinander (1887).

[4] Hammer, E., Über die geographisch wichtigsten Kartenprojektionen insbesondere die zenitalen Entwürfe (1889), p. 119. The Hammer projection of North and South America has since been calculated and constructed (Winkel, Oswald, Flächentreue, schiefachsige Zylinderprojektion mit längentreuem Grundkreis für eine Karte von Nord-, Mittel- und Südamerika. Petermanns Mitt. vol. 55, [1909], pp. 329 and 379, plates 40 and 44.)

[5] Hammer, E., Zwei praktische Beispiele schiefachsiger zylindrischer Kartennetzentwürfe. Petermanns Mitt., vol. 50 (1904), p. 277.

Zöppritz[6] discusses the various types of cylindrical equal-area projections, and presents figures and tables for the meridional type. Groll[7] publishes a small map of the Atlantic Ocean projected on the meridional type. Eriksson[8] also reproduces a map of North and South America on the meridional equal-area projection. The meridian of 100° W of Greenwich is used as the great circle of tangency. The same region is represented on an oblique cylindrical equal-area projection, and is the example which Hammer suggested in his "Kartenprojektionen" of 1889.

It was not until the publication of the new Swedish atlas, "Nordisk Världsatlas,"[9] that the cylindrical equal-area was considered worthy of a place beside other familiar projections used in representing continental areas. Nine important maps are here made on this projection, two normal, five meridional,[10] and two oblique. In discussing these latter Rosén says, "Probably it is only the extent of the work of computation that makes such transverse projections relatively rare in geographic atlases."

USES AND LIMITATIONS OF THE MERIDIONAL TYPE

In the meridional projection the portion of the earth's surface near the meridian of tangency is represented accurately, but the areas at and near the points of intersection of the axis of the cylinder are greatly distorted when projected to the cylinder. The Atlantic Ocean is shown in figure 5 on the meridional form. The circle of tangency is a meridian which passes as nearly as possible through the center of the ocean. The axis of the cylinder cuts the surface of the sphere on the equator at 135° W and 45° E longitude. These are the points of extreme distortion which, on development, become straight lines along the edge of the map. The land which happens to be near either of these points is almost shapelessly distorted. It happens here that the eastern coast of Africa falls within this zone of very great distortion. Most of the coasts are near the central zone where the true shape

[6] Zöppritz, K., Leitfaden der Kartenentwurfslehre, erster Teil, die Projektionslehre (revised by A. Bludau, 1912), p. 159.

[7] Groll, M., Kartenkunde; I. Die Projektionen (ed. 2; revised by Dr. Otto Graf, 1922), p. 116.

[8] Eriksson, J. V., Om Kartenprojektioner: en översikt (1925), pp. 29, 30.

[9] Zetterstrand, S., och Rosén, K., Nordisk Världsatlas (1926).

[10] The map of South America is on the projection urged by Hammer, in his "Kartenprojektionen."

is approximated. Aside from its property of equal area, this projection of the Atlantic Ocean possesses another property of considerable value (common to all cylindrical equal-area projections). All straight lines perpendicular to the central meridian, the circle of tangency of

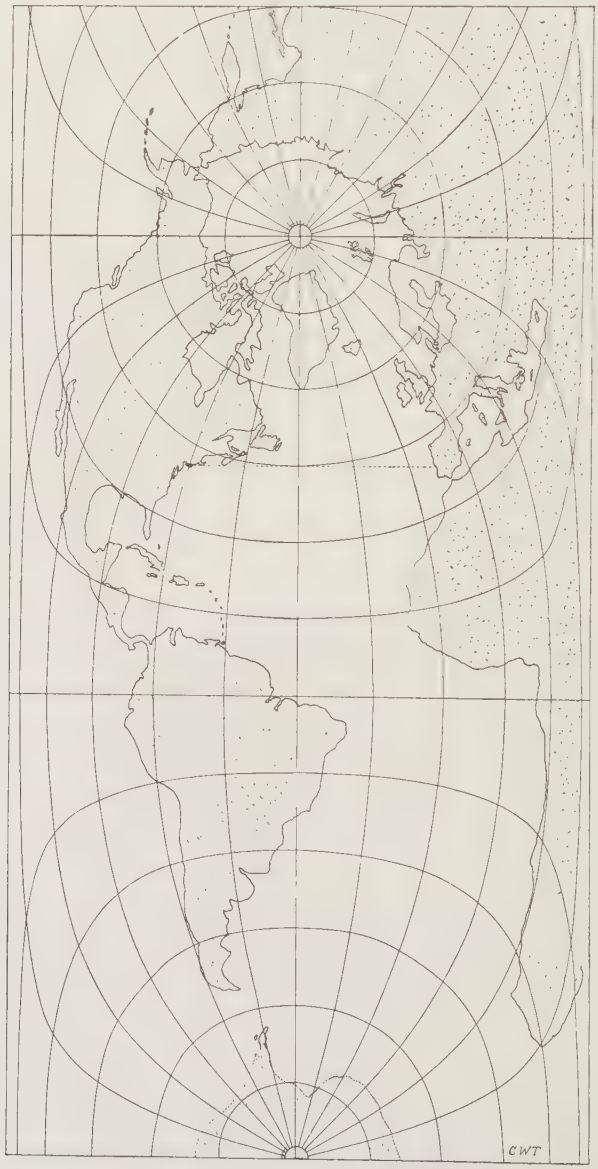


Fig. 5.—Meridional cylindrical equal-area projection of the Atlantic and Arctic oceans. Circle of tangency on meridian of 45° W longitude.

the cylinder, are great circles; thus shortest distances straight across the ocean, being great circles, are straight lines. The straight line drawn from New York to Lisbon is part of a great circle and in consequence indicates the shortest distance between the two places.

OBLIQUE CYLINDRICAL EQUAL-AREA PROJECTIONS

It is, however, in its most generalized form, where the circle of tangency of the cylinder is skewed at any acute angle, that the cylindrical equal-area projection becomes most useful. For instance, one may choose a great circle tangent so as to place the greatest possible land surface within the area of little distortion, and to have the least important lands and ocean bodies on the edge where the distortion is great. This, obviously, is accomplished by causing the axis of the cylinder to intersect the surface of the sphere on the oceans as far as possible from coast lines. The greatest distortion occurs along the margins of the map, and cannot be avoided or even reduced (fig. 6). The fact that the distortion is in two belts at the edge, when considered with the good representation near the center, proves to be of very great significance, for with some manipulation this circle of little distortion may be shifted to any desired position. It is this characteristic which makes the cylindrical one of the most useful of the equal-area projections.

It is the insoluble problem of distortion which makes impossible an entirely satisfactory equal-area projection of any sort. Goode[11] has effected a compromise in his interrupted homolographic and homolosine projections, securing equivalence and a minimum of distortion throughout the map at the cost of continuity. Frequently this interruption of the map is undesirable.

All equal-area world maps have regions in which the distortion of shape is relatively slight. Therefore the most satisfactory way out of the difficulties of distortion is to place the continental masses of special interest within these regions. In the cylindrical equal-area projection this region of little distortion is a belt entirely around the

[11] Goode, J. P., Studies in Projections; Adapting the Homolographic Projection to the Portrayal of the Earth's Surface Entire. Bull. Geog. Soc. Phila., vol. 17 (1919), pp. 103–113; The Homolosine Projection. Ann Am. Assoc. Geog., vol. 15 (1925).

earth; a belt which can include the area adjacent to any great circle. In no other projection is this possible.[12]

The method of skewing has been applied to other types of projections. Hammer advocates the use of a transverse equal-spaced projection for the North Pacific Ocean,[13] and of the transverse conic projection for Africa,[14] Japan, and South America.[15] Deetz and Adams[16] discuss transverse Mercator and transverse polyconic projections.

Some defects of the cylindrical equal-area projection should be here considered. The world map is inconveniently shaped, being more than three times as long as wide. The ratio of length to width can be decreased and at the same time the belt of little distortion widened somewhat by having the cylinder, instead of encircling the sphere (as previously considered), cut through it, forming a secant cylindrical rather than a tangent cylindrical projection. In the simplest case, that of the equatorial form, the cylinder is not tangent at the equator but intersects the sphere, passing through two parallels at equal distances north and south of the equator. The width of the

[12] For discussions of distortion and distortion indicatrix in the various equal-area projections, see the following articles:

(1) Behrmann, W., Zur Kritik der flächentreuen Projektionen der ganzen Erde und einer Halbkugel (München Akademie Sitzungsberichte der Math.-Physik. Klasse, vol. 39, 1909). Discusses distortion indicatrix for all world equal-area projections. Good bibliography of German literature relating to the subject.

(2) Behrmann, W., Die beste bekannte flächentreue Projektion der ganzen Erde (Petermans Mitt., vol. 56:2, 1910, p. 141). Shows that the cylindrical equal-area projection secant at 30° is the best yet devised for the whole world.

(3) Zöppritz, K., Die Wahl der Projektion für Atlanten und Handkarten (Ztschr. d. Ges. Erdk. Berlin, vol. 19, 1884).

(4) Hammer, E., Über die Planisphäre von Aitow und verwandte Entwürfe insbesondere neue flächentreue ähnlicher Art (Petermanns Mitt., vol. 38, 1892, p. 85).

[13] Hammer, E., Entwürfe für eine Karte des Nordpazifischen Ozeans. Petermanns Mitt., vol. 69 (1923), p. 18.

[14] Hammer, E., Über Projektionen der Karte von Afrika. Ztschr. d. Ges. für Erdk. zu Berlin, vol. 24 (1889).

[15] Hammer, E., Über die geographisch wichtigsten Kartenprojektionen insbesondere die zenitalen Entwürfe, pls. 2 and 4:2.

[16] For illustrations of the transverse Mercator see Deetz, C. C., and Adams, O. S., Elements of Map Projection. U. S. Coast and Geodetic Surv. Spec. Publ. 68, p. 115.

For illustration of transverse polyconic see plate 2 in the foregoing reference, or Adams, O. S., General Theory of Polyconic Projections, U. S. Coast and Geodetic Surv., Spec. Publ. 57, opp. p. 7.

Of the polyconic Deetz and Adams say: "If the map should have a predominating east-and-west dimension, the polyconic properties may still be retained, by applying the developing cones in a transverse position. A great circle at right angles to a central meridian at the middle part of the map can be made to play the part of the central meridian, the poles being transferred (in construction only) to the equator. By transformation of coordinates a projection may be completed which will give all polyconic properties in a transverse relation. This process is, however, laborious and has seldom been resorted to."—Elements of Map Projection, p. 62.

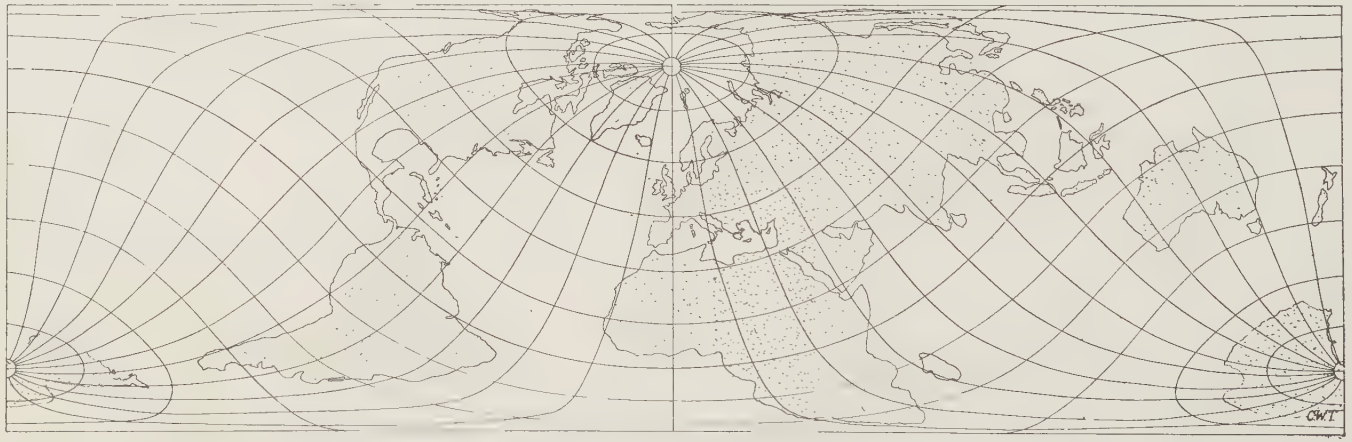


Fig. 6.—Oblique cylindrical equal-area projection of the world. Circle of tangency cuts the equator at 90° W and 90° E of Greenwich at angles of 45°. The axis of the cylinder emerges in the North Pacific at 180° of longitude and 45° N latitude, and in the South Atlantic on the Prime Meridian at 45° S latitude.

projection is the same as before, equal to the length of the axis of the sphere, but its length is less than the circumference of the sphere, equal to the length of the parallels chosen for intersection. The transformation is performed by multiplying the dimension to be reduced by the cosine of the latitude of secancy. The resulting projection, obviously, will be of smaller scale than the original. In order to preserve the scale and the property of equivalence the width must be increased at the same rate as the length is reduced. The width is thus divided by the cosine of the latitude of secancy. The projection in which the cylinder is secant at 30° N and S of the equator is proposed as being, so far as is now known, the best equal-area projection of the whole world.[17] All of the cylindrical equal-area projections in Nordisk Världsatlas were developed from cylinders secant rather than tangent to the sphere. According to Professor Rosén the lengths have been reduced by amounts varying from the cosine of 15° to the cosine of 30°, and in the maps of South America and Africa by a constant factor, ¾. There has been, however, no apparent corresponding increase in the length.

If less than the entire earth's surface is to be represented the awkward shape of the projection does not prove an inconvenience, as is illustrated by the base maps of California[18] and of the continents of Eurasia and Africa (see map).[19] The sort of projection shown in figure 6, if made on a secant rather than a tangent cylinder, should be useful in representing various areal distributions. It is continuous, is not too badly distorted for this purpose, and the polar regions are shown in the interior of the map. This last quality is of great significance in representing distributions where relative location is important. The anthropologists are confronted with the problem of showing primary race distribution in such a way that the relation between the races of eastern Asia and the American continents, and between those of southern Africa and Australia can be seen clearly. For their purpose a projection showing the Arctic region as a unit is highly desirable.

The transverse cylindrical equal-area projection is valuable in that it can show with little distortion a strip of the earth's surface

[17] Behrmann, W., Die beste bekannte flächentreue Projektion der ganzen Erde. Petermanns Mitt., vol. 56:2 (1910), p. 141.

[18] The base map of California by Thornthwaite, no. 9 of the University of California Map Series, is on the meridional cylindrical equal-area projection. The 120th meridian is used as the circle of tangency.

[19] The base map of Eurasia and Africa, included here, is issued also as no. 10 in the University of California Map Series. This map supplies for the first time a satisfactory base for the entire desert belt of the Old World, the so-called Levantine or Mohammedan World.

Fig. 7.—The great circle used for the circle of tangency is the one which borders the Pacific Ocean around what is often called "the rim of the world." In the projection of this cylinder, one end of the axis passed through the center of the continent of Africa. This point, on development, was 'spread' over the entire length of the map; Africa is therefore distorted quite beyond recognition. The Western Hemisphere is in the central belt of little distortion and has its true shape remarkably well preserved. Indeed, the two continents of the Western Hemisphere are shown in their relationship to one another better than in many projections which can show one hemisphere only. Again, all straight lines perpendicular to the length of the map are great circles.

along any great circle, and at the same time represent all the rest equivalent as to area (fig. 7). The projections here presented picture the earth in a variety of positions. The few poses so far worked out make it clear that many problems of relative location may be solved by means of this projection.

GEOMETRIC CONSTRUCTION OF THE PROJECTION

The cylindrical equal-area projection can be constructed by direct geometric means. Figures 2, 3, and 4 illustrate the procedure. In these figures the left halves of the orthographic hemispheres are developed cylindrically; the relation between orthographic hemisphere and corresponding cylindrical development is basic to the construction, and may be seen from figure 2. The circle of tangency is first drawn to scale. Since the scale is constant along this line, equidistant perpendiculars erected to it provide means for locating points in a direction parallel to it. These perpendiculars are meridians in the equatorial type (fig. 2). It is readily seen that they correspond to the meridians represented by the ellipses of the orthographic hemisphere, in the same figure. The two sets of lines, ellipses on the orthographic hemispheres, and straight lines perpendicular to the circle of tangency of the cylindrical development, are equivalent, and serve as means for locating points on meridians and parallels, through which these latter lines may be drawn. In figures 3 and 4, they are the broken construction lines. In these figures, any point at which a construction line on the orthographic hemisphere cuts the parallels and meridians may be carried across by simple projection to the corresponding construction line on the cylindrical development. Here it gives a point on the corresponding meridian or parallel. Through the points so found, the lines desired are drawn. It should be noted that the points located are not the points of intersection of meridians and parallels.

The procedure, then, is first, the drawing of the orthographic hemisphere in the scale desired. The edges of the cylindrical development are determined by the length of the arc of the circle of tangency necessary for the particular map, and by the projection of the edges of the orthographic hemisphere. The meridians and parallels of the map are then constructed in the manner indicated in the preceding paragraph. It will be seen from inspection of the drawings that the remainder of the projection involves only the repetition of the parts shown, appropriately reversed.

CONSTRUCTION OF THE PROJECTION BY MEANS OF RECTANGULAR COORDINATES

The great labor involved in the use of the auxiliary orthographic diagram makes the geometric construction of the transverse forms of the cylindrical equal-area projection impracticable. Mathematical tables could be calculated and tabulated with little difficulty, so that the transverse cylindrical projections would be made permanently available in convenient form. Unfortunately in the transverse projection a new set of tables must be calculated for each angle of skewness of the circle of tangency. The meridional type is really but a special type of transverse projection in which the angle of skewness is 90°, and tables can be calculated by using the same formulae as for the general type.

DEVELOPMENT OF THE FORMULAE

In figure 8, the circle of tangency of the cylinder cuts the equator of the sphere at A and forms with it $\angle\ \theta$. When the cylinder is developed the circle of tangency becomes the x,x' axis of the transformed coördinates. The y,y' axis is shown at right angles to x,x'. P is any point, of longitude λ and latitude φ. P' is the projection of P onto the cylinder. It is required to determine the coordinates of point P' with reference to the axes, x,x' and y,y'. AT is the required distance on the x,x' *axis* and equals R times arc AT measured in radians, R being the radius of the sphere. The ordinate $P'T$ is the projection of the arc PT on the tangent cylinder, and is equal to R sin arc PT. It is required to find AT and $P'T$ in terms of the longitude and latitude of P, and of $\angle\ \theta$.

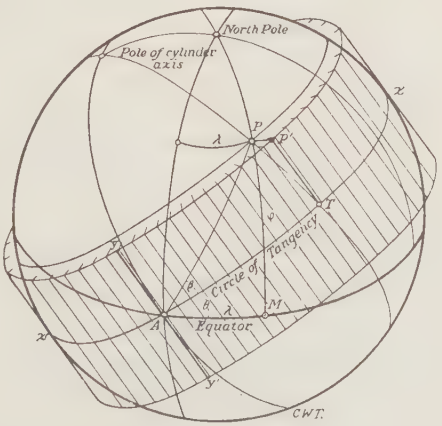


Fig. 8

TO FIND AT—

In spherical right triangle ATP,

1. $\text{Tan } AT = \cos \beta \cdot \tan AP$

$$= \cos \beta \cdot \frac{\sin AP}{\cos AP}.$$

and in spherical right triangle AMP,

2. angle $MAP = \beta + \theta$, or $\beta = MAP - \theta$

3. $\cos MAP = \dfrac{\tan \lambda}{\tan AP}$

$$= \tan \lambda \cdot \frac{\cos AP}{\sin AP}$$

4. $\cos AP = \cos \varphi \cdot \cos \lambda.$

5. $\sin MAP = \dfrac{\sin \varphi}{\sin AP}$

6. $\cos (MAP - \theta) = \cos MAP \cdot \cos \theta + \sin MAP \cdot \sin \theta$

Substituting in (1),

$$\text{Tan } AT = (\cos MAP. \cos \theta + \sin MAP. \sin \theta) \cdot \frac{\sin AP}{\cos AP} \quad (6)$$

$$= (\tan \lambda \cdot \frac{\cos AP}{\sin AP} \cdot \cos \theta + \frac{\sin \varphi}{\sin AP} \cdot \sin \theta) \cdot \frac{\sin AP}{\cos AP} \cdot \quad (3)(5)$$

by canceling,

$$\text{Tan } AT = \left(\frac{\tan \lambda \cdot \cos AP \cdot \cos \theta}{\cos AP} + \frac{\sin \varphi \cdot \sin \theta}{\cos AP} \right)$$

$\cos AP$ disappears in the first member; substituting (4) in the second member we have

$$\text{Tan } AT = \tan \lambda \cdot \cos \theta + \frac{\sin \varphi \cdot \sin \theta}{\cos \varphi \cdot \cos \lambda}$$

but, $\dfrac{\sin \varphi}{\cos \varphi} = \tan \varphi$

Therefore,

$$\text{Tan } AT = \tan \lambda \cdot \cos \theta + \frac{\tan \varphi \cdot \sin \theta}{\cos \lambda}$$

AT in radians is the value desired.

To FIND $P'T$—

In spherical right triangle ATP,

1. $\sin PT = \sin \beta \cdot \sin AP$

and in spherical right triangle AMP,

2. $\cos MAP = \dfrac{\tan \lambda}{\tan AP}$

$$= \tan \lambda \cdot \frac{\cos AP}{\sin AP}$$

3. $\cos AP = \cos \varphi \,.\, \cos \lambda.$

4. $\sin MAP = \dfrac{\sin \varphi}{\sin AP}$

5. $\sin (MAP - \theta) = \sin MAP \,.\, \cos \theta - \cos MAP \,.\, \sin \theta.$

Substituting in (1),

$$\sin PT = (\sin MAP \,.\, \cos \theta - \cos MAP \,.\, \sin \theta) \,.\, \sin AP$$
$$= \left(\frac{\sin \varphi}{\sin AP} \,.\, \cos \theta - \tan \lambda \,.\, \frac{\cos AP}{\sin AP} \,.\, \sin \theta\right) \,.\, \sin AP$$

by cancellation,

$$\sin PT = \sin \varphi \,.\, \cos \theta - \tan \lambda \,.\, \cos AP \,.\, \sin \theta$$
$$\tan \lambda = \frac{\sin \lambda}{\cos \lambda}$$
$$\text{and } \cos AP = \cos \varphi \,.\, \cos \lambda \quad (3)$$

substituting,

$$\sin PT = \sin \varphi \,.\, \cos \theta - \frac{\sin \lambda}{\cos \lambda} \,.\, \cos \varphi \,.\, \cos \lambda \,.\, \sin \theta.$$
$$= \sin \varphi \,.\, \cos \theta - \sin \lambda \,.\, \cos \varphi \,.\, \sin \theta$$

Therefore

$$P'T = R \,.\, \sin PT.$$
$$P'T = R \,.\, (\sin \varphi \,.\, \cos \theta - \sin \lambda \,.\, \cos \varphi \,.\, \sin \theta).$$

In the meridional type, $< \theta = 90°$ and the formulae become simplified as follows:

$$\sin \theta = 1.$$
$$\cos \theta = 0.$$
$$P'T = R \,.\, (\sin \varphi \,.\, 0 - \sin \lambda \,.\, \cos \varphi \,.\, 1.)$$
$$= -\mathrm{R} \,.\, (\sin \lambda \,.\, \cos \varphi)$$
$$\mathrm{Tan}\, AT = \tan \lambda \,.\, 0 + \frac{\tan \varphi \,.\, 1}{\cos \lambda}$$
$$= \frac{\tan \varphi}{\cos \lambda}$$

THE TABLES

The following tables give rectangular coordinates for points of intersection of parallels and meridians at intervals of 5° of latitude and longitude in a half-hemisphere, on an oblique cylindrical equal-area projection. The plane of the great circle of tangency intersects the plane of the equator at an angle of 40°. X and Y have their usual meanings, being coordinates on the axes of abscissas and ordinates respectively. The origin of coordinates is taken at the point of intersection of the circle of tangency with the equator where

the positive segment of the $X =$ axis lies north of the equator. North latitude is designated plus; south latitude, minus. Longitude is expressed in degrees east of the origin. The same coordinates may

Coordinates for Transverse Cylindrical Equal Area Projection

Angle $\theta = 40°$

Lat.	Long. 0		Long. 5		Long. 10		Long. 15	
	X	*Y*	*X*	*Y*	*X*	*Y*	*X*	*Y*
0	.0000	−.00000	.0669	−.0560	.1341	−.1116	.2024	−.1664
5	.0561	.06676	.1227	.01095	.1899	−.04443	.2577	−.09897
10	.1128	.13302	.1789	.07785	.2452	.02310	.3121	−.03082
15	.1704	.19827	.2353	.14416	.3005	.09046	.3665	.03757
20	.2298	.26200	.2932	.20936	.3566	.15711	.4206	.10567
25	.2903	.32375	.3525	.27298	.4139	.22255	.4757	.17297
30	.3552	.38302	.4142	.33450	.4733	.28636	.5332	.23894
35	.4229	.43938	.4786	.39349	.5346	.34795	.5911	.30310
40	.4945	.49240	.5466	.44948	.5989	.40690	.6522	.36496
45	.5713	.54167	.6190	.50206	.6673	.46274	.7164	.42403
50	.6536	.58682	.6964	.55081	.7400	.51507	.7845	.47988
55	.7426	.62751	.7796	.59538	.8180	.56349	.8575	.53209
60	.8389	.66341	.8697	.63540	.9020	.60760	.9361	.58023
65	.9433	.69427	.9675	.67059	.9933	.64710	1.0213	.62396
70	1.0556	.71985	1.0727	.70069	1.0923	.68168	1.1138	.66295
75	1.1758	.73994	1.1868	.72544	1.1999	.71105	1.2147	.69688
80	1.3032	.75441	1.3087	.74468	1.3160	.73503	1.3247	.72552
85	1.4355	.76313	1.4373	.75806	1.4399	.75340	1.4437	.74863
90	1.5708	.76604	1.5708	.76604	1.5708	.76604	1.5708	.76604
−5	−.0561	−.06676	.0105	−.12257	.0777	−.17795	.1460	−.23249
−10	−.1128	−.13302	−.0468	−.18819	.0201	−.24294	.0875	−.29686
−15	−.1704	−.19827	−.1056	−.25238	−.0398	−.30608	.0267	−.35897
−20	−.2298	−.26200	−.1664	−.31464	−.1021	−.36689	−.0369	−.41833
−25	−.2903	−.32375	−.2298	−.37452	−.1675	−.42495	−.1047	−.47452
−30	−.3552	−.38302	−.2964	−.43154	−.2371	−.47968	−.1780	−.52710
−35	−.4229	−.43938	−.3674	−.48527	−.3112	−.53081	−.2551	−.57566
−40	−.4945	−.49240	−.4430	−.53532	−.3912	−.57790	−.3395	−.61984
−45	−.5713	−.54157	−.5242	−.58128	−.4776	−.62060	−.4314	−.65931
−50	−.6536	−.58682	−.6120	−.62283	−.5713	−.65857	−.5314	−.69376
−55	−.7426	−.62751	−.7071	−.65964	−.6731	−.69153	−.6402	−.72293
−60	−.8389	−.66341	−.8101	−.69142	−.7825	−.71922	−.7583	−.74659
−65	−.9433	−.69427	−.9212	−.71795	−.9017	−.74144	−.8849	−.76458
−70	−1.0556	−.71985	−1.0405	−.73901	−1.0283	−.75802	−1.0187	−.77675
−75	−1.1758	−.73994	−1.1670	−.75444	−1.1609	−.76883	−1.1571	−.78300
−80	−1.3032	−.75441	−1.2994	−.76414	−1.2973	−.77379	−1.2976	−.78330
−85	−1.4355	−.76313	−1.4347	−.76800	−1.4352	−.77280	−1.4364	−.77763
−90	−1.5708	−.76604	−1.5708	−.76604	−1.5708	−.76604	−1.5708	−.76604

be used in constructing the remaining three-quarters of the earth's surface. Coordinates are expressed as fractions of the radius of the sphere. In the construction of a map, the mean radius of the sphere is multiplied by the scale factor for the particular map, and the

Lat.	Long. 20		Long. 25		Long. 30		Long. 35	
	X	*Y*	*X*	*Y*	*X*	*Y*	*X*	*Y*
0	.2720	−.2199	.3429	−.2717	.4165	−.3215	.4924	− .3687
5	.3266	−.14295	.3971	−.20386	.4669	−.25341	.5442	−.30052
10	.3784	−.08349	.4494	−.13451	.5204	−.18349	.5937	−.23007
15	.4331	−.01408	.5006	−.06412	.5701	−.11217	.6414	−.15785
20	.4933	.05541	.5515	.00673	.6190	−.04001	.6882	−.08445
25	.5387	.12450	.6024	.07755	.6673	.03247	.7330	−.01116
30	.5934	.19263	.6542	.14776	.7164	.10469	.7801	.06373
35	.6493	.25929	.7068	.21686	.7659	.17611	.8264	.13737
40	.7068	.32399	.7609	.28430	.8171	.24620	.8738	.20997
45	.7674	.38625	.8174	.34958	.8697	.31441	.9230	.28097
50	.8311	.44551	.8770	.41220	.9250	.38021	.9738	.34983
55	.8991	.50141	.9404	.47170	.9835	.44317	1.0280	.41604
60	.9721	.55249	1.0082	.52759	1.0460	.50271	1.0853	.47807
65	1.0515	.60136	1.0815	.57947	1.1138	.55844	1.1464	.53846
70	1.1376	.64466	1.1615	.62694	1.1874	.60993	1.2150	.59375
75	1.2351	.68304	1.2494	.66963	1.2691	.65676	1.2898	.64452
80	1.3352	.71623	1.3462	.70724	1.3590	.69860	1.3730	.69039
85	1.4483	.74397	1.4533	.73945	1.4591	.73512	1.4661	.73100
90	1.5708	.76604	1.5708	.76604	1.5708	.76604	1.5708	.76604
− 5	.2155	−.28577	.2871	−.33738	.3633	−.38693	.4375	−.43404
−10	.1585	−.34953	.2280	−.40055	.3019	−.44953	.3790	−.49611
−15	.0948	−.41062	.1655	−.46066	.2368	−.50871	.3156	−.55439
−20	.0294	−.46859	.0986	−.51727	.1704	−.56401	.2458	−.60845
−25	− .0410	−.52300	.0265	−.56995	.0960	−.61503	.1710	−.65866
−30	− .1166	−.57341	− .0523	−.61828	.0137	−.66135	.0832	−.70231
−35	− .1987	−.61947	− .1384	−.66190	− .0774	−.70265	− .0128	−.74139
−40	− .2883	−.66081	− .2336	−.70050	− .1786	−.73860	− .1213	−.77483
−45	− .3863	−.69709	− .3386	−.73376	− .2915	−.76893	− .2432	−.80237
−50	− .4939	− 72813	− .4539	−.76144	− .4165	−.79341	− .3793	−.82381
−55	− .6109	−.75361	− .5803	−.78332	− .5533	−.81185	− .5288	−.83898
−60	− .7377	−.77333	− .7167	−.79923	− .7007	−.82411	− .6882	−.84775
−65	− .8727	−.78718	− .8610	−.80907	− .8549	−.83010	− .8534	−.85008
−70	−1.0134	−.79504	−1.0097	−.81276	−1.0114	−.82977	−1.0175	−.84595
−75	−1.1574	−.79684	−1.1589	−.81024	−1.1650	−.82312	−1.1749	−.83536
−80	−1.3005	−.79259	−1.3043	−.80158	−1.3113	−.81022	−1.3206	−.81843
−85	−1.4393	−.78229	−1.4425	−.78681	−1.4471	−.79114	−1.4527	−.79526
−90	−1.5708	−.76604	−1.5708	−.76604	−1.5708	−.76604	−1.5708	−.76604

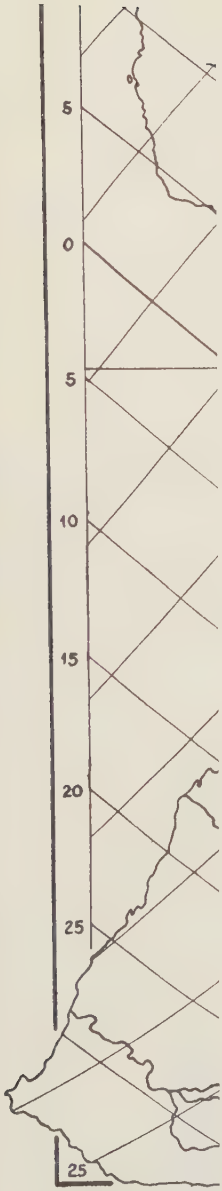
product used as a constant by which the coordinates given in the tables are multiplied to give the coordinates of the points on the map. The signs of the coordinates are the usual signs in the four quadrants of the field of coordinates.

Lat.	Long. 40		Long. 45		Long. 50		Long. 55	
	X	*Y*	*X*	*Y*	*X*	*Y*	*X*	*Y*
0	.5713	−.4132	.6536	−.4545	.7400	−.4924	.8302	−.5157
5	.6213	−.34484	.7019	−.38603	.7857	−.42377	.8727	−.45778
10	.6690	−.27388	.7473	−.31459	.8278	−.35190	.9119	−.38552
15	.7147	−.20083	.7900	−.24076	.8680	−.27736	.9486	−.31033
20	.7589	−.12626	.8316	−.16511	.9064	−.20071	.9835	−.23279
25	.8023	−.05071	.8718	−.08818	.9433	−.12252	1 0169	−.15346
30	.8450	.02520	.9116	−.01061	.9797	−.04341	1.0495	−.07297
35	.8854	.10093	.9515	.06706	1.0156	.03603	1.0815	.00806
40	.9320	.17589	.9916	.14422	1.0526	.11520	1.1138	.08905
45	.9771	.24951	1.0326	.22028	1 0891	.19349	1.1467	.16935
50	1.0239	.32124	1.0751	.29466	1.1271	.27031	1.1804	.24837
55	1.0734	.39053	1.1196	.36681	1.1670	.34508	1.2124	.32550
60	1.1257	.45682	1.1670	.43615	1.2091	.41721	1.2526	.40014
65	1.1822	.51966	1.2179	.50218	1.2545	.48617	1.2924	.47174
70	1.2438	.57854	1.2735	.56440	1.3040	.55144	1.3355	.53976
75	1.3119	.63300	1.3349	.62230	1.3587	.61250	1.3835	.60366
80	1.3875	.68266	1.4035	.67548	1.4200	.66891	1.4373	.66298
85	1.4733	.72712	1.4815	.72352	1.4898	.72022	1.4989	.71714
90	1.5708	.76604	1.5708	.76604	1.5708	.76604	1.5708	.76604
− 5	.5175	−.47836	.6015	−.51955	.6900	−.55729	.7873	−.59130
−10	.4596	−.53992	.5445	−.58063	.6349	−.61794	.7307	−.65156
−15	.3959	−.59737	.4814	−.63730	.5727	−.67390	.6708	−.70687
−20	.3220	−.65026	.4104	−.68911	.5020	−.72471	.6013	−.75679
−25	.2464	−.69821	.3296	−.73568	.4200	−.77002	.5192	−.80096
−30	.1571	−.74084	.2368	−.77665	.3237	−.80945	.4203	−.83901
−35	.0541	−.77783	.1297	−.81170	.2097	−.84273	.3002	−.87070
−40	− .0611	−.80891	.0032	−.84058	.0736	−.86960	.1524	−.89575
−45	− .1937	−.83383	− .1419	−.86306	− .0867	−.88985	− .0267	−.91399
−50	− .3429	−.85240	− .3072	−.87898	− .2719	−.90333	− .2370	−.92527
−55	− .5070	−.86449	− .4890	−.88821	− .4756	−.90994	− .4689	−.92952
−60	− .6813	−.87000	− .6798	−.89067	− .6862	−.90961	− .7028	−.92668
−65	− .8578	−.86888	− .8692	−.88636	− .8886	−.90237	− .9186	−.91680
−70	−1.0292	−.86116	−1.0472	−.87530	−1.0716	−.88826	−1.1002	−.89994
−75	−1.1888	−.84688	−1.2069	−.85758	−1.2298	−.86738	−1.2575	−.87622
−80	−1.3325	−.82616	−1.3468	−.83334	−1.3637	−.83991	−1.3829	−.84584
−85	−1.4594	−.79914	−1.4672	−.80274	−1.4759	−.80604	−1.4855	−.80912
−90	−1.5708	−.76604	−1.5708	−.76604	−1.5708	−.76604	−1.5708	−.76604

The values in the table were computed and used for the construction of the map of Eurasia and Africa. The origin, in this map, is at the intersection of the meridian of Greenwich with the equator.

Lat.	Long. 60		Long. 65		Long. 70		Long. 75	
	X	*Y*	*X*	*Y*	*X*	*Y*	*X*	*Y*
0	.9250	−.5567	1.0239	−.5826	1.1272	−.6040	1.2342	−.6209
5	.9637	−.48779	1.0579	−.51359	1.1557	−.53496	1.2566	−.55176
10	.9989	−.41519	1.0888	−.44069	1.1813	−.46182	1.2764	−.47843
15	1.0318	−.33943	1.1170	−.36444	1.2048	−.38517	1.2944	−.40151
20	1.0623	−.26110	1.1435	−.28543	1.2267	−.30560	1.3100	−.32144
25	1.0920	−.18077	1.1688	−.20424	1.2470	−.22368	1.3270	−.23509
30	1.1205	−.09907	1.1932	−.12149	1.2671	−.14008	1.3427	−.15468
35	1.1487	−.01662	1.2168	−.03783	1.2863	−.05541	1.3567	−.06922
40	1.1769	.06597	1.2406	.04613	1.3055	.02969	1.3712	.01678
45	1.2051	.14805	1.2648	.12973	1.3250	.11456	1.3858	.10264
50	1.2342	.22900	1.2892	.21236	1.3445	.19767	1.4009	.18772
55	1.2645	.30822	1.3145	.29337	1.3648	.28106	1.4160	.27139
60	1.2965	.38507	1.3410	.37213	1.3864	.36140	1.4323	.35297
65	1.3305	.45901	1.3698	.44807	1.4093	.43900	1.4492	.43187
70	1.3677	.52946	1.4006	.52063	1.4342	.51326	1.4681	.50749
75	1.4090	.59586	1.4359	.58916	1.4614	.58361	1.4887	.57924
80	1.4553	.65775	1.4736	.65325	1.4925	.64952	1.5120	.64659
85	1.5045	.71461	1.5184	.71236	1.5283	.71049	1.5388	.70902
90	1.5708	.76604	1.5708	.76604	1.5708	.76604	1.5708	.76604
−5	.8820	−.62131	.9857	−.64711	1.0949	−.66848	1.2086	−.68528
−10	.8331	−.68123	.9419	−.70673	1.0574	−.72786	1.1790	−.74447
−15	.7764	−.73597	.8904	−.76098	1.0126	−.78171	1.1429	−.79805
−20	.7098	−.78510	.8281	−.80943	.9573	−.82960	1.0975	−.84544
−25	.6292	−.82827	.7511	−.85174	.8875	−.87118	1.0387	−.88259
−30	.5291	−.86611	.6527	−.88753	.7950	−.90612	.9579	−.92072
−35	.4031	−.89538	.5239	−.91659	.6679	−.93417	.8401	−.94798
−40	.2432	−.91883	.3514	−.93867	.4855	−.95511	.6562	−.96802
−45	.0587	−.93529	.1213	−.95361	.2216	−.96878	.3537	−.98070
−50	−.2024	−.94464	−.1681	−.96128	−.1341	−.97597	−.1073	−.98592
−55	−.4709	−.94680	−.4869	−.96165	−.5250	−.97396	−.6082	−.98363
−60	−.7327	−.94175	−.7810	−.95469	−.8552	−.96542	−.9678	−.97385
−65	−.9608	−.92953	−1.0175	−.94047	−1.0917	−.94954	−1.1874	−.95667
−70	−1.1452	−.91024	−1.1952	−.91907	−1.2549	−.92644	−1.3247	−.93221
−75	−1.2904	−.88402	−1.3279	−.89072	−1.3698	−.89627	−1.4167	−.90064
−80	−1.4047	−.85107	−1.4285	−.85557	−1.4544	−.85930	−1.4821	−.86223
−85	−1.4960	−.81165	−1.5074	−.81390	−1.5193	−.81577	−1.5318	−.81724
−90	−1.5708	−.76604	−1.5708	−.76604	−1.5708	−.76604	−1.5708	−.76604

Lat.	Long. 80		Long. 85		Long. 90	
	X	*Y*	*X*	*Y*	*X*	*Y*
0	1.3442	−.6330	1.4570	−.6403	1.5708	− .6428
5	1.3599	−.56240	1.4646	−.57114	1.5708	−.57358
10	1.3733	−.49038	1.4716	−.49759	1.5708	−.50000
15	1.3855	−.41318	1.4780	−.42025	1.5708	−.42262
20	1.3968	−.33284	1.4835	−.33972	1.5708	−.34202
25	1.4076	−.24996	1.4890	−.25660	1.5708	−.25881
30	1.4178	−.16519	1.4946	−.17153	1.5708	−.17365
35	1.4277	−.07916	1.4989	−.08516	1.5708	−.08716
40	1.4373	.00748	1.5039	.00187	1.5708	.00000
45	1.4471	.09405	1.5088	.08888	1.5708	.08715
50	1.4570	.17892	1.5138	.17522	1.5708	.17364
55	1.4672	.26443	1.5190	.26023	1.5708	.25883
60	1.4780	.34690	1.5242	.34324	1.5708	.34202
65	1.4896	.42675	1.5301	.42303	1.5708	.42262
70	1.5019	.50334	1.5365	.50084	1.5708	.50000
75	1.5158	.57610	1.5431	.57420	1.5708	.57358
80	1.5312	.64449	1.5510	.64322	1.5708	.64280
85	1.5493	.70796	1.5600	.70732	1.5708	.70711
90	1.5708	.76604	1.5708	.76604	1.5708	.76604
− 5	1.3270	−.69592	1.4480	−.70466	1.5708	−.70710
−10	1.3064	−.75642	1.4376	−.76363	1.5708	−.76604
−15	1.2811	−.80972	1.4245	−.81679	1.5708	−.81916
−20	1.2488	−.85684	1.4076	−.86372	1.5708	−.86602
−25	1.2060	−.89746	1.3849	−.90410	1.5708	−.90631
−30	1.1281	−.93123	1.3520	−.93757	1.5708	−.93969
−35	1.0524	−.95792	1.2994	−.96392	1.5708	−.96592
−40	.8916	−.97732	1.1993	−.98293	1.5708	−.98480
−45	.5713	−.98929	.9439	−.99446	1.5708	−.99619
−50	− .0669	−.99372	− .0334	− 99842	0.0000	−1.00000
−55	− .7554	−.99059	−1.0582	−.99479	−1.5708	−.99619
−60	−1.1202	−.97992	−1.3270	−.98358	−1.5708	−.98480
−65	−1.3064	−.96179	−1.4300	−.96551	−1.5708	−.96592
−70	−1.4009	−.93636	−1.4841	−.93886	−1.5708	−.93970
−75	−1.4655	−.90378	−1.5176	−.90568	−1.5708	−.90630
−80	−1.5109	−.86433	−1.5405	−.86560	−1.5708	−.86602
−85	−1.5443	−.81830	−1.5577	−.81894	−1.5708	−.81915
−90	−1.5708	−.76604	−1.5708	−.76604	−1.5708	−.76604



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LANDSLIDE LAKES OF THE NORTHWESTERN GREAT BASIN

BY

RICHARD JOEL RUSSELL

INTRODUCTION

Landslides play a significant and major rôlė in the formation of lakes in at least one part of North America, namely, the northwestern Great Basin. Here, over approximately 10,000 square miles, the surface is covered for the most part by a relatively thin sheet of basaltic lava. Beneath the basalt, in concordant relationship, are beds of andesitic agglomerate and tuff.

Wherever the local relief is sufficient for cañon-trenching, the few tens or hundreds of feet of basalt soon become "rim rocks," capping walls of more readily eroded material. The normal widening of the cañons takes place largely as the result of "sapping action," the steepness of cañon sides being determined by the relation of the cinder and ash beds, excellent media for basal recession, to lava caps. A talus cover of spalls weathered from the basaltic rims checks the sapping to some extent, particularly where cañons and valleys are shallow and the thickness of the basalt is an important proportion of the whole depth. This protection remains as long as slopes are less steep than the angle of repose of the talus, which ranges between 30° and 33° in the northwestern Great Basin for the materials under discussion. Streams with steep gradients, established in the andesitic materials, lower their beds rapidly and exhibit a characteristically diminished talus cover on the cañon walls. Under commonly existing conditions there is, therefore, active undermining of the lava cap, the valley walls being literally oversteepened. The growth in width of

such valleys is thus largely a matter of slide, creep, and slump. The streams are ordinarily competent to carry away débris furnished them by the two latter processes but slides occasionally overwhelm the streams so completely that lakes are formed. Several of these lakes are described in the following pages (fig. 1). The examples here selected are for the most part from the Warner Range of northeastern California, a region in which the writer has spent parts of six out of the last seven field seasons.

EXISTING LAKES

Clear Lake which is shown on the Alturas, California, Quadrangle of the United States Geological Survey, is located on Mill Creek two miles northeast of Jess Valley in the southern part of the Warner Range. It is one-half mile long and about 200 yards in width at its widest part, which occurs near its western end. Soundings at this end show a depth of 90 feet. Eastward it shallows gradually toward the inlet. The longitudinal profile of the lake bottom fits exactly, without break in gradient, into the profile of the parts of Mill Creek above and below the lake and the barrier dam at the deep end. The cañon sides continue downward with unbroken slopes beneath the lake surface, the dead trees standing on these submerged slopes being members of a forest which occupies a part of the cañon.

Where Mill Creek enters the lake the cañon is about 1,000 feet deep. A basalt cap, composing the upper 250 feet of its walls, stands up as a conspicuous rim. Below this, andesitic materials, covered for the most part by talus, are here and there visible. Westward the cañon deepens with correspondingly steeper sides, so that less and less talus is able to maintain itself on the slopes. Above the lake great bands of buff, white, and gray andesitic tuff and agglomerate are exposed and can be followed westward well beyond the end of the lake.

Near the lower end of the lake sheer cliffs of freshly exposed bedrock 100 feet or more in height scar the cañon walls on both sides. These scars are visible for miles to the southwest and are often the first features of the landscape noted by a person entering Jess Valley. At the immediate base of each scar are blocks of basalt, andesitic agglomerate, and tuff measuring as much as 20 or even 40 feet in diameter. Down slope the valley floor is exceedingly irregular, due to a succession of hummocks and pits formed by a mass of blocks similar to those at the cliff bases. These materials, derived from the

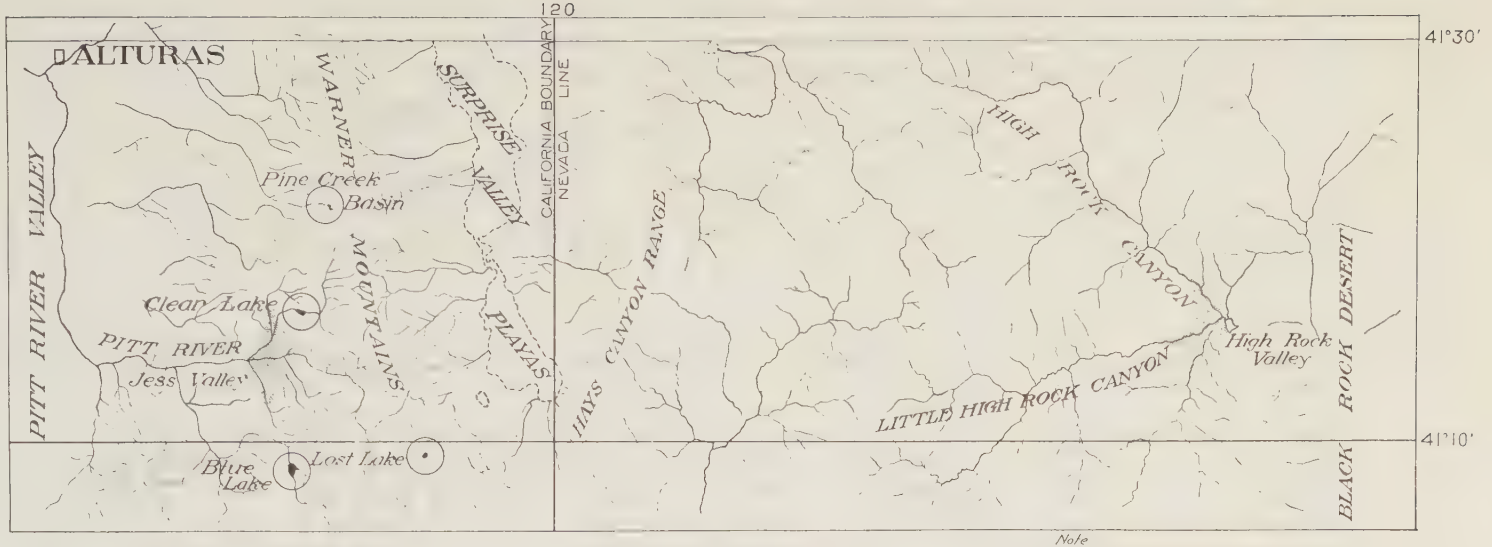
120
41°30'
41°10'
ALTURAS
PITT RIVER VALLEY
WARNER MOUNTAINS
SURPRISE VALLEY
CALIFORNIA BOUNDARY
NEVADA LINE
Pine Creek Basin
Clear Lake
PITT RIVER
Jess Valley
Blue Lake
Lost Lake
PLAYAS
HAYS CANYON RANGE
HIGH ROCK CANYON
LITTLE HIGH ROCK CANYON
High Rock Valley
BLACK ROCK DESERT
Russell: Landslide Lakes
Drainage from Forest Service and U.S.G.S. Maps
Note
Extinct Lakes, approx extent by dots
Present Lake in High Rock Valley left white
0
5
10

Fig. 1

two sides of the cañon, meet and form the Clear Lake dam, a part of which, with its hummocky topography, is shown in plate 26*a*. White firs and yellow pines are well established on the landslide fill, the pines attaining diameters of 2 feet and more. It thus appears that the lake is scarcely more than a century old. The scars, slide materials, and lake shores are remarkably fresh. It is said locally that there are Indian traditions concerning the slides and the origin of the lake.

Furthermore, a delta forming at the head of the lake is still in its infancy, covering but an acre or so. The drainage basin of Mill Creek above the delta has an area of about 20 square miles, for the most part surfaced by steep slopes of readily eroded andesitic materials. That these materials are actually being eroded rapidly is shown by the muddy condition of the stream throughout the greater part of each year. Under these conditions, filling at the head of the lake must be rapid, and the remarkably small size of the delta seems thus to indicate that the lapse of but a century would be fully ample to account for it.

The two landslides which share in the Clear Lake dam are symmetrically situated across the valley from each other. They are both about a half-mile from the center of the dam. The linear extent of fill along the stream axis is about one-third of a mile. To all appearances the slides were simultaneous, at least nothing was observed which might be interpreted as evidence to the contrary. As the whole Warner Range area is one of recent seismic activity, evidenced by numerous recent fault scarps, it seems likely that the slides were "set off" by an earthquake. Possibly one slide started the other. They are located where the cañon had been most deeply cut. Here talus from the basalt rims above was least effective to check the sapping, and the lower walls of the cañon became basally oversteepened. Preparation for sliding had advanced equally on the two sides of the symmetrical cañon so that when started both walls shared about equally in furnishing slide débris.

At the lake outlet Mill Creek winds between hummocks as high as 40 or 50 feet for about one-half mile at comparatively gentle gradient. Beneath its clear waters is a stream-bed mosaic of blocks as tightly fitting as those of a wind-swept desert. The even current is apparently able to carry away débris less than an inch in diameter, allowing larger blocks and slabs to settle snugly into a pavement which protects underlying material from erosion.

At the lower end of the channel that passes through the hummocks the stream plunges abruptly over falls 60 feet high and thence down several cataracts into a gorge 90 feet deep (pl. 26*b*). Here the true heterogeneity of the landslide débris is most readily appreciated. Material varying in grade-size from fine sand to blocks 30 or 40 feet in diameter is thrown together without the slightest evidence of sorting. The sides of the gorge are far steeper than the angle of repose of the materials which have been cut through. We are here, therefore, in an area of exceedingly rapid topographic change. It is said that the falls have receded 30 feet in the last fifteen years. As an irrigation ditch intake is located close to the head of the falls the people in Jess Valley will have fairly accurate data on falls recession for several years to come. It seems unlikely that the rate of 2 feet per year will last long. The whole gorge and the falls are of comparatively recent origin. For a number of years Clear Lake had been dammed artificially and its waters raised 3 or 4 feet. In either 1907 or 1909, both years of heavy floods in that region, a particularly severe flood carried away the dam, and the rush of water cut most of the existing gorge. It is said that previously the channel had been changing comparatively slowly, although falls 10 or 15 feet high are known to have existed at one place. It seems probable that another period of less rapid erosional change will be established long before the falls recede the necessary half-mile to tap the lake.

Blue Lake, about 10 miles due south of Clear Lake, and also shown on the Alturas Quadrangle, has a history almost identical with that of Clear Lake, even as to recency of origin. A single slide, originating on cliffs to the west, caused the damming of Parsnip Creek. The scar of this slide is probably even more striking than either of those above the Clear Lake dam.

Lost Lake, about 10 miles southeast of Clear Lake, on the eastern front of the Warner Range (fig. 2), is not shown on the Quadrangle but it occupies a valley mapped on the Modoc-Lassen County boundary line and is situated about a mile and a half west of the National Forest boundary. It is on the north fork of a stream called Bares Creek, this fork being locally known as Silver Creek.

Silver Creek has been dammed by material derived from the slope to the south. The scar of the slide is not as distinct as those thus far described but the outline of the fan-shaped slide itself is not at all obscure. Not only is the slide easily identifiable on the basis of heterogeneity of rock materials and topographic surface, but it is also

outlined on the basis of vegetational changes. White fir notably prefer the slide surface to other situations. They not only grow more profusely there but also extend up to the very apex of the slide several hundreds of feet above their upper growth limits elsewhere on the cañon wall.

Lost Lake is much older than either Clear or Blue lakes. Its water surface is about ten acres while its delta has grown to fifteen. The

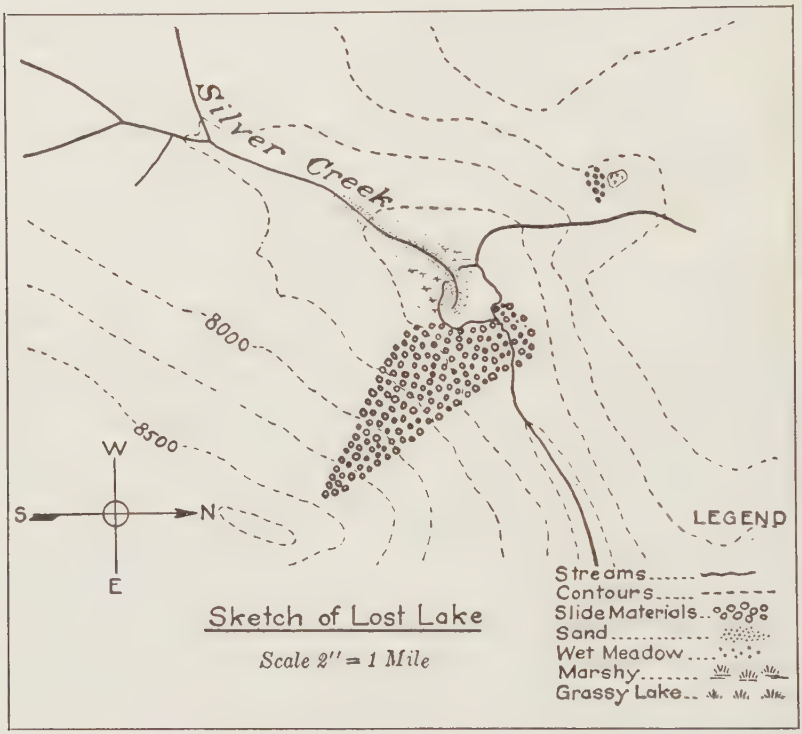

Fig. 2

present maximum depth of the lake is but 15 or 20 feet. The profile of Silver Creek projected under the delta, lake, and slide suggests an original depth of 60 feet. Sediment contributed by Silver Creek seems to be responsible for nearly all of the filling. The upper portion of the delta, now a quarter of a mile back from the head of the lake, is comparatively dry meadow land, while coniferous trees, such as grow in the valley bottom immediately upstream, have not yet established foothold on it. Followed downstream this grassy meadow becomes moister and in about half the distance to the lake is so saturated that it is impassable. Immediately at the stream sides are

sandy natural levees densely overgrown by willows. The levees continue far into the lake, forming a lobe which swings from an easterly to a southerly direction and almost succeeds in dividing the lake in two. The drainage basin of Silver Creek above Lost Lake has less than one-quarter the area of that of Mill Creek above Clear Lake. The slopes of the Silver Creek drainage basin are, on the whole, less steep than those of Mill Creek basin and the surface materials are less readily eroded. Silver Creek is a comparatively clear stream

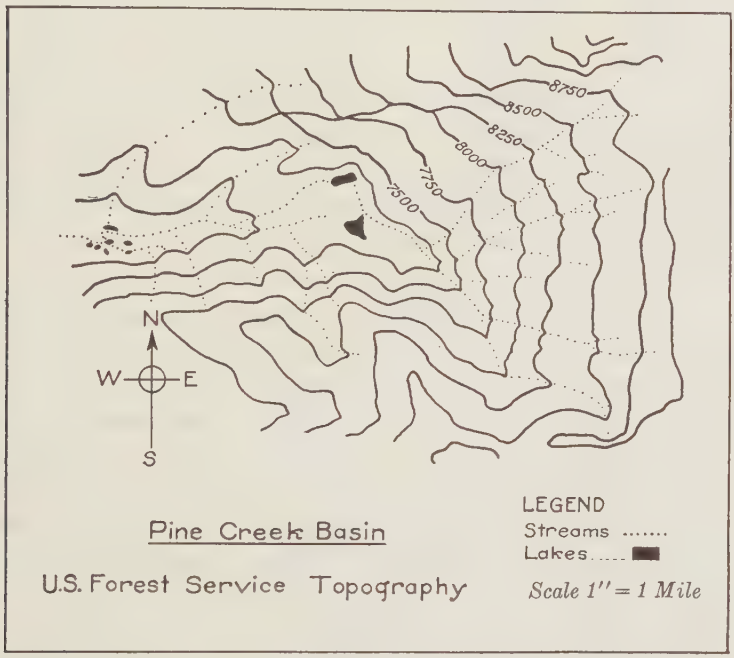

Fig. 3

during most of the year. The large and well-formed delta certainly suggests that Lost Lake has existed much longer than has Clear Lake.

The outlet of Lost Lake is similar to that of Clear Lake but the length of the channel with paved floor is now only about 150 feet. Below this the gradient suddenly increases and Silver Creek plunges turbulently down cascades for several hundred yards. Here the landslide fill is being rapidly carried away. It is an open question whether the extinction of the lake will result from filling or from tapping, but in either case the date will not be remote.

Pine Creek Basin Lakes (fig. 3) are located about six miles north of Clear Lake. On the Alturas Quadrangle the basin is suggested by the valley just south of the ridge extending west from Warren Peak.

Pine Creek Basin is one of several striking "Headwater Basins"[1] on the west slope of the Warner Range. From its upper margin, toward the east, where the basin is 2 miles wide, it narrows westward for nearly 4 miles, merging gradually into a cañon very similar to that at the head of Clear Lake. The south wall of the basin is 1000 feet high where best developed and though steep is in comparatively stable condition, being for the most part covered by dense forest. The relatively barren north wall is slightly less high but is much steeper. Its upper part is kept cliffy for nearly three miles as a result of frequent landslides. Below the cliffs is an extensive accumulation of landslide débris (pl. 27*a*). About 2 miles east of the cañon where slides are developed to a maximum degree, the local relief between the hills and pits in the débris often reaches 100 feet. About 2 miles toward the west and at a distance of three-quarters of a mile toward the east the landslide topography becomes indistinguishable, agreeing with the reduced height of the basin wall.

The floor of Pine Creek Basin slopes westward with an average and apparently quite uniform gradient of 250 feet per mile. Accumulations of landslide débris irregularly cover this floor, dividing the main basin into a number of smaller basins. The smallest basins of all are the pits in the hummocky débris itself. These at times enclose small ponds. Larger than these are basins composed of several pits having low divides between. These, too, often contain small ponds, which dry out during the greater part of each year. Of still larger size are the basins which have been caused by slides of sufficient magnitude to extend from the north to the south basin wall. In these are lakes which last throughout the whole or the greater part of each year. Two of these lakes now exist in the area of maximum slide development. When filled, each of these has a water area of from ten to fifteen acres. Farther west, where the main basin is narrower, a half-dozen or more of such lakes exist, but the sum of their combined areas is less than that of either of the large lakes upstream.

All of the Pine Creek Basin lakes are shallow, the deepest not exceeding 20 feet when full. The projection of the profile of Pine Creek beneath the Basin suggests that not more than 30 or 40 feet of sediment has collected anywhere in it.

Both of the larger lakes maintain surface outlets during their high-water stages, in the spring, after the thawing of winter snows. It is

[1] Bryan, K., U. S. Geological Survey, Bull. 730-B, p. 52, 1922, explains how such basins are formed.

said that ten or fifteen years ago these lakes maintained these outlets during all, or the greater part, of the summer. In the summers of 1924 and 1925, when observed by the writer, and for the last few years in general, according to report, the period of high-water stage has been very short, evidently due to the development of subterranean outlets. Pine Creek connects all of the major and some of the minor lakes in its basin by a circuitous surface course through irregular slide débris. In the summer, parts of the channel at the lake outlets become dry, but invariably water is replenished a short distance beyond, on the lower sides of the barrier dams, where large springs are located. It is said that lake trout successfully negotiate some of the subterranean passages as they pass in migratory flight from drying lakes to those better supplied with water. In no case does siphon action seem to have been established in these hidden channels. The springs at their lower ends are remarkable for their uniformity of flow. They are characterized by steady outflow as long as the lakes are completely filled, and often long after the lakes have become practically dry. Pine Creek, in the basin, flows throughout the year. After the lakes have dried, the actual channel continues across the lake bottoms to the upper ends of the next lower subterranean outlets. Plate 27*a* shows one of these channels entrenching its delta and flowing through irregular pools toward an obscure underground outlet.

The lake basin shown in plate 27*a* offers an exceptional opportunity for the study of delta growth. During the high-water stages the muddy and swollen inlet stream proceeds to build a delta, but when the lake lowers, in response to lessened flow of this stream, the delta annually becomes entrenched. At the lowest stage about 90 per cent of the lake floor is exposed and the delta is left completely uncovered, the condition shown in plate 27*b*. For the greater part of that season of the year when the ground is unfrozen the unprotected delta is subject to the attack of subaerial erosion as well as to entrenchment by the stream. In spite of this the delta is growing more rapidly than it is being consumed. The attack of subaerial erosive forces over most of its surface is indeed ineffective, as delicate shore lines cut during the period of receding waters are not modified to any great extent during the dry summers. These shore lines are shown in plate 27*b*. They are most conspicuously developed during the higher stages of the lake, but later on the rate of surface lowering speeds up and shore lines are obscure or absent. In part this may be due to reduced ability of the waves to notch the shores because of diminished reach during the lower stages.

The exposed part of the delta during the high-water stages is nothing more than the summit area of two curvilinear parallel ridges. During the low stages the stream flows between these, entrenched as deeply as 6 or 7 feet. Each ridge is convexly rounded at the crest quite asymmetrically toward the steep slope of entrenchment and has a gentle outer slope away from the stream. The outer slope is concave for most of its length. Upstream these ridges become normal natural levees through which the stream flows in a narrow winding meadow.[2] The layers of stratified silt which make up the levees thin out as they grade down slope without interruption into the sediment of the lake floor. This ideal condition of stratification is considerably modified along the sides of the delta by the annual silt layers that fill the notches cut by the waves of the preceding summer. In front of the delta, stratification is greatly disturbed by slumping, or downward flowing, of wet mud, a process which continues well into the summer, the shore lines being obscured, erased, or distorted thereby.

A second, small delta is being built below the main delta in a small pool which remains on the lake floor throughout the summer. Its materials are derived from the entrenchment of the larger delta above and its form is essentially that of the large delta minus the shore lines.

EXTINCT LAKES

Lake Jess (fig. 4) is an extinct landslide lake which once filled Jess Valley, the largest valley on the southwestern slopes of the Warner Range. The center of the valley is about 22 miles southeast of Alturas.

Jess Valley is one of several tectonic basins on the west slope of the range. Structurally it is a westward tilting block terminated by a fault scarp on its western side. The stratigraphy is that described for Clear Lake, which is about two miles northeast. The floor of the valley is essentially flat and is about 6 miles long and 2½ miles wide. Three major and a number of minor streams flowing into the valley unite centrally on its western side and become the headwater stream of the south fork of the Pitt River. The Pitt is antecedent to the fault scarp west of the valley and flows across the upthrown block in a narrow gorge. Conditions are as favorable for sapping in the gorge walls as at Clear or Blue lakes. Toward its eastern end the depth

[2] The position of this meadow is obscured in plate 27*b* by firs and pines which have established themselves on some old slide débris at the head of the lake.

of the gorge commonly exceeds 500 feet, and at places 750 feet. Plate 28*a* shows part of the gorge nearly 10 miles west of Jess Valley.

The landslide of about 160 acres which formed Lake Jess took place within one-half mile of the Jess Valley end of the Pitt River gorge.

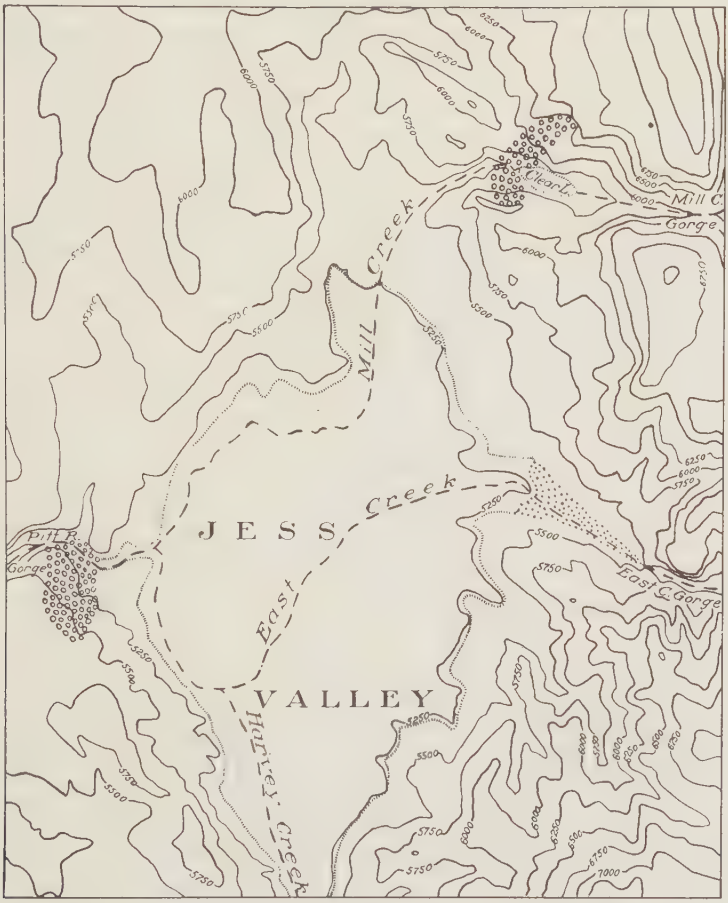

Fig. 4

The linear extent of slide surface now fronting on the river is nearly one-half mile. A rough estimate of the amount of material moved during the sliding approximates forty-five million cubic yards. It seems likely that this slide was set off by an earthquake as there are several active faults in the immediate vicinity. The surface topography of the slide débris is similar to that found in the areas described previously except that the hills and depressions are more subdued

and rounded. Some of the depressions enclose small temporary ponds. The density of vegetative cover is somewhat greater on the moved than on the unmoved area immediately surrounding the slide but a greater degree of readjustment has taken place here than on the more recent slide surfaces. Junipers and yellow pines growing on the slide seem to be as large and as old as those scattered about on adjacent surfaces.

Slides similar to the one which formed Lake Jess have occurred farther west in the ten-mile Pitt River gorge. Several of these formed lakes which have long since disappeared, but their records remain as terraces on the gorge walls. In one of these water bodies over a hundred feet of sediment has collected. Four or five major and several minor terraces of this kind are arranged in the longitudinal profile of the valley like so many steps of a stairway. An old slide terminates the downstream end of each terrace.

The Lake Jess slide was much larger and is closer to the valley than any of the others. It blocked the river at an elevation of 300 feet or more above the level of the next slide to the west and is well over a mile upstream from the upper end of the sediments which collected behind that slide. It succeeded in backing water not only into the half-mile of gorge above it but also into the valley to the extent of forming a lake 5 miles long, from north to south, 3 miles in maximum east-west width, and with a surface area of about 8 square miles.

Lake Jess remained at one stage long enough to cut a shore line on all sides of the valley. Plate 28*b* shows the shore line on the fault scarp at the west. There the width of the wave-cut bench averages 20 feet. Toward the northern end of the eastern side of the lake, at the old Ivy Post Office, the bench is fifty feet wide. Farther south, at Coyote Creek, it is still wider. At the outlet the elevation of the shore line is 164 feet above the present river channel. Observations made by means of a small field transit show little or no variation in shore-line level along the western scarp face. Toward the east, however, the upward slope is about 10 feet per mile, indicating that the whole northwestern Great Basin is a region of recent crustal instability.

During the shore-line cutting stage one of the major tributary streams, East Creek, built a delta a mile long and 500 yards wide at its lower end. The delta sediments are chiefly coarse sands and conglomerates. The upper surface of the delta slopes toward the valley with a gradient of 160 feet per mile, some of which is due to tilting

in that direction. At the head of the delta East Creek emerges from an exceedingly deep and narrow gorge. Remnants of a corrasion terrace leading to the delta surface are visible on the sides of the gorge for several hundred feet back from its mouth. The stream has now cut about 30 to 40 feet below this old terrace and is entrenched in its delta as much as 50 feet in some places.

The depth of the lake-fill in Jess Valley is not definitely known as drill holes have never been sunk through it. If the depth is calculated on the basis of a tilted block of basalt which in its east to west dip disappears beneath the recent fill, a minimum depth of 500 feet will be found for the western side of the valley. The dip of the basalt is by no means uniform, however, and possible depths can be calculated which double the above estimate. There is no assurance that dips are continued at depth nor that faulting does not materially disturb the whole of the covered surface. Thus little value can be placed on such calculations. At the outlet, quite close to the slide, drilling has been done in order to investigate the possibilities for a dam site. The maximum depth drilled was 60 feet but the bottom of the lake sediment was not reached. It is said that most of the material taken out of the hole was finely bedded white or gray clay and mud, and that organic material notably decreased in amount below the upper 10 feet or so. There is certainly no reason to suppose lesser depths of sediment in the valley when a thickness of 60 feet exists on the upthrown block west of there. The life of Lake Jess must have been comparatively long as judged by the shore lines and the East Creek delta. While it would not be fair to assume that the presumably great depth of sediment in the valley all accumulated in this particular lake, at least the upper 60 feet was so collected. The Pitt in maintaining its antecedent course across the block to the west may have at times been blocked by faulting, with the result of impounding the valley, but the temporary lakes so formed would not add to the fill in the outlet between the Lake Jess slide and the fault zone. We can therefore safely assign the upper 60 feet of sediment to Lake Jess itself.

The draining of Lake Jess apparently took place rapidly without any notable resting stages as but one shore line marks the level of the lake. This suggests that once the Pitt succeeded in eroding the steep western side of the slide to the extent of tapping the lake, the further removal of slide material was rapid. After the waters had been drained the force of the Pitt was greatly reduced so that erosion since that time has been no more rapid than erosion during the period of

the lake's existence. Little dissection of the lake sediments has taken place. The larger streams are entrenched 5 or 6 feet but the valley still serves as their flood plain. The landslide barrier is still protecting the valley from deep entrenchment by the Pitt River tributaries. Though the gradient of the Pitt is steep on the downstream side of the slide and the river plunges down slide débris in step-like cascades for several hundred yards, it will be a great length of time before any appreciable amount of the valley sediment is removed from behind this barrier.

Lake High Rock is a name here given for a lake which once occupied a portion of High Rock Valley, on the boundary between Washoe and Humboldt counties, Nevada, at the latitude of 41° 17′ N. High Rock Valley is about 55 miles east of Jess Valley. It appears unnamed on the Long Valley, Nevada, Quadrangle of the United States Geological Survey. The small playa now existing in the valley is locally called High Rock Lake.

High Rock Valley is about 5 miles long, from north to south, and is 2 miles wide, from east to west. Its floor is about 1000 feet below surrounding summits. The eastern valley wall is a fault scarp covered to some extent by talus from basaltic rims above, shown in plate 29. Immediately at the foot of the talus is the playa floor of High Rock Lake.[3] West of the lake floor the valley rises gently for some distance and then by two sudden jumps, apparently fault scarps, the surface level becomes that of a plateau which extends westward some 36 miles to become the summit area of the Hays Cañon Range, just east of the California-Nevada state line. This plateau is deeply entrenched by several streams, but notably by High Rock and Little High Rock creeks, each having developed cañons 1000 feet deep for a few miles toward their lower ends. These cañons converge and enter High Rock Valley.

The topographers of the Long Valley Quadrangle neglected to indicate, on the mountain block east of High Rock Valley, a cañon as large, deep, and impressive as that of High Rock Creek itself. On the Black Rock Desert side of the range, to the east, the cañon is suggested on the topographic map but toward the summit the hint becomes quite obscure. Its omission is probably due to its being cut off from High Rock Valley by a huge landslide, which caused the permanent abandonment of the stream that once carried the surplus water of the valley eastward to the area now called desert. The slide

[3] On the Long Valley Quadrangle the lake is incorrectly shown as being farther toward the center of the valley.

area is immediately east of the southern end of High Rock Lake, as shown on the Quadrangle. It may or may not be a matter of chance that the axes of the lower segments of the High Rock cañons, if projected across the valley, meet at the entrance of the abandoned cañon.

The landslide which blocked this original outlet of High Rock Valley covers about one-half mile of the original stream channel and fills the cañon to a depth of 600 feet, or more. The surface of the slide is hummocky and exceedingly rough. The basalt masses which took part in the original slide have now been weathered into coarse talus, the characteristic covering material of the whole slide surface, nearly everywhere standing on 30° slopes.

Under present climatic conditions High Rock Lake remains dry for most of the year and, judging from white water-lines on the black talus of its eastern shores, seldom reaches maximum depths of more than two or three feet. The region is sufficiently arid that the valley functions as the evaporating pan for the excess waters of between 500 and 600 square miles of surrounding territory and has no need for an outlet. If the abandoned channel were now connected with the valley, it would receive waters for only short periods, immediately after heavy rainfall, and possibly in the spring from the melting of the light snow blanket on the plateau to the west.

In the past, however, the outlet must have carried considerable amounts of water. Entering a faulted block, exactly as the Pitt River enters the block west of Jess Valley, the old stream was capable of maintaining its antecedent course across an actively uplifting mountain mass. This is certainly suggestive of greater erosive force than the channel could possibly have today. In addition to this there is still more concrete evidence of greater amounts of water in the past in that the blocking of the outlet caused surplus waters to back up, forming Lake High Rock.

In filling up to the lowest point on its basin rim Lake High Rock grew to a depth of some 450 to 500 feet. An outlet thus established was not across slide débris but at a point about 3 miles to the north of the old cañon. During the life of the lake an outlet channel was cut to the depth of 400 to 450 feet, a notable achievement for lake waters flowing out upon a surface of basalt. In this period a delta several miles long was built in High Rock Cañon, benches were cut around the shores, and sediments were deposited to unknown depth in the valley.

Lake High Rock was not quite completely drained by the down-cutting of its outlet stream. With a barrier of but 40 or 50 feet remaining, climatic conditions had changed so that the amount of water furnished the basin no longer provided any excess for outflow. The level of the lake lowered and a portion of the outlet stream reversed so as to flow back toward the lake. The remaining portion of the outlet stream is in comparatively fresh condition, with a channel far too pretentious for the small amount of water it carries toward Soldier Meadows, at the north end of one of the arms of the Black Rock Desert. The depth of the outlet gorge testifies to the great length of time the lake existed. The fresh nature of the abandoned channel indicates, in somewhat less certain terms, the comparatively short span of time that has elapsed since the disappearance of the lake.

The original blocked cañon has suffered comparatively little change, particularly in view of its antiquity. No trace of the original stream channel remains. The only watercourse present in the upper end of the cañon is a relatively feeble channel, apparently in use during the existence of the lake. This has been more recently covered, to a very considerable degree, by drifting sand. The accumulation of talus along the cañon sides and the presence of sand in its center seem to be the only changes of any significance now going on in the shadowy gloom and silence of this deep and abandoned cañon.

EXPLANATION OF PLATES

PLATE 26

a. Surface of landslide dam at the western end of Clear Lake.

b. Falls of Mill Creek at the head of the gorge, Clear Lake landslide dam. The hummock area is in the background.

a

b

PLATE 27

a. Landslide débris, lake floor, and entrenched delta in Pine Creek Basin.

b. Dry lake, entrenched delta, and shore lines, Pine Creek Basin.

a

b

PLATE 28

a. Pitt River Gorge about ten miles west of Jess Valley.

b. View across Jess Valley toward Pitt River Gorge, showing shore lines of Lake Jess.

a

b

PLATE 29

High Rock Valley playa hugging escarpment east of the valley. The embayment toward the right is the entrance of the cañon blocked by landslide.

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THE PAMPA—A NATURAL OR CULTURALLY INDUCED GRASS-LAND?

BY

OSCAR SCHMIEDER

The Quechua word *pampa* means plain, and in Argentina the landscape thus named forms a part of the extensive plains that slope gently from the Andes toward the Paraguay-Paraná-La Plata Basin and the Atlantic Coast. The term Pampa early became identified with the grass-lands which the Spaniards encountered in the eastern part of the greater lowlands. The western border of this grass-land is, however, difficult to locate since it merged gradually and irregularly into the scrub steppe of the western plains.[1] This fact explains why it is that different attempts to represent graphically the border of the Pampa by a simple line have resulted only in a remarkable disagreement about the areal extension of the Pampean landscape (fig. 1).

The exact delimitation of the Pampa has become still more difficult in modern times since European immigration has greatly altered primitive natural conditions. The original prairie has largely disappeared. What was once the grass-land of the Pampa has now become in the main the agricultural area of Argentina. The coincidence is, however, not complete (fig. 1). The European immigrant who plowed the Pampa did not halt at the limits of the open grass-land. He advanced with his field into the surrounding tree steppe until the increasing aridity imposed a limit to his activities. The area now under cultivation has therefore a larger surface than the prairies once occupied (fig. 1).

[1] Cruz, Luis de la, Viage de la Concepción de Chile hasta la ciudad de Buenos Aires, 1806, *in* P. de Angelis, Col. de obras y documentos relativos a la historia del Rio de la Plata (Buenos Aires, 1836), vol. 1, part 2, pp. 1–216.

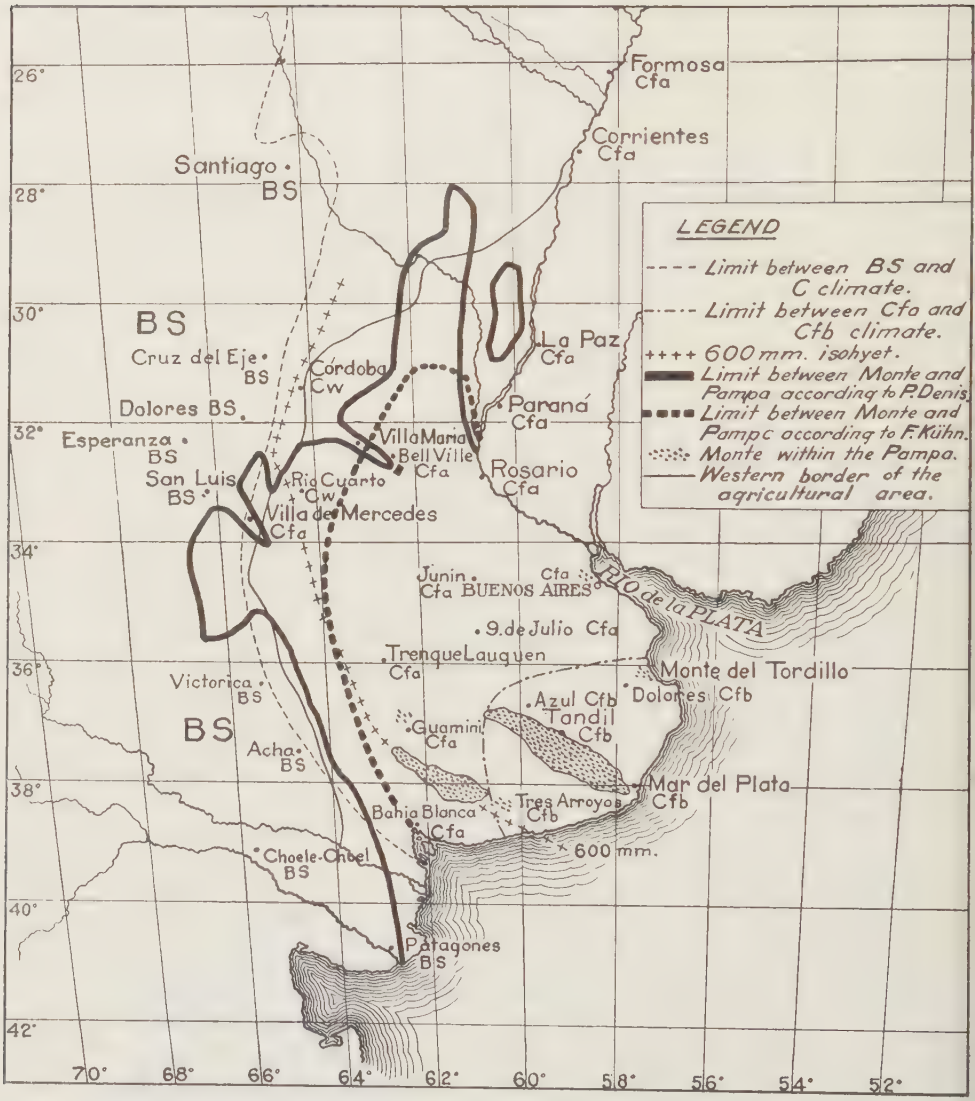

Fig. 1. The climatic features of the Argentine plains as related to vegetational and agricultural areas.

There will always be some uncertainty about the limits of the area, but that does not preclude the conception of the Pampa as a South American landscape of pronounced individuality. The geographical features which make up this individuality are largely cultural, and only to a very small extent, natural. Only a genetic study which tries to reconstruct the successive alterations of the landscape as the result of the long interaction between man and his habitat can do justice to the Pampa as it is today.

Edaphic elements.—The extent of the Pampa, as it has been defined above, has no relation to any particular underground conditions. The Argentine plains in their totality, from the Rio Colorado in the south as far as the Chaco in the north, are composed of young sediments in horizontal position. D'Orbigny has called the upper series of these sediments the "Pampa formation." The Pampa in the geologic sense thus extends far beyond the borderline of the Pampa prairies.

The Pampa formation[2] is characterized by a rhythmic alternation of horizons consisting of fluvial deposits, fluvial and lacustrine loess, and eolian loess with some intercalations of volcanic ash. The upper horizon, however, which forms the actual land surface far beyond the grass-lands, is almost everywhere a thick layer of true eolian loess. Hence the character of the grassy Pampa cannot be accounted for in terms of surface and soil.

The climate.—The climate[3] of the Argentine plains north of the Rio Colorado is mainly under the influence of the unequal heating of the land and the adjacent Atlantic Ocean in summer and winter. From the Atlantic coast of the Pampa toward the interior, a continual change of climatic conditions takes place. The greater part of the Pampa shows a typical *Cfa*[4] climate, with hot summers (Buenos Aires, warmest month, February, average, 23.5° C; Bahia Blanca, warmest month, January, average, 23.1° C), and "mild" winters (Buenos Aires, coldest month, June, average, 10.1° C; Bahia Blanca, coldest month, July, average 8.4° C). Only in the southeast the *Cfb* climate with cooler summers (warmest month below 22° C) appears.

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[2] A good list of the main literature on the Pampa formation is contained in F. Kühn, Fundamentos de fisiografía Argentina (Buenos Aires, 1922), pp. 55–57.

[3] Davis, Walter G., Argentine meteorologic service (Buenos Aires, 1914); Climate of the Argentine Republic (Buenos Aires, 1910).

[4] The symbols used are those given by W. Köppen, Die Klimate der Erde, 1923.

The diurnal range of temperature is considerable in the Pampa, and not even in the coast region is this contrast mitigated by the neighborhood of the ocean. Not only differences in radiation and insolation produce changes of temperature; tongues of cold air from the south, so-called *pamperos,* frequently push into the lowland causing sudden lowering of the temperature.

Toward the interior the summer temperature rises rapidly, and in the plains from San Juan to Santiago del Estero, the closed isotherm of 30° C for January delimits the hottest area of South America.

The general increase of temperature from the Atlantic coast toward the west and northwest is accompanied by a decrease of rainfall in the same direction. In the Pampa itself the annual precipitation decreases from approximately 1,000 mm. on the coast to 600 mm. in the interior, an amount which is, however, subject to great nonperiodic changes from year to year. Forty-year records for Buenos Aires show a minimum of 547 mm. in 1893 and a maximum of 2,025 mm. in 1900. In the western plains, beyond the limits of the Pampa proper, the annual amount of rainfall decreases rapidly to less than 250 mm.

An important change in the seasonal distribution of rainfall may also be noted in passing from the Atlantic toward the interior plains. The Pampa has a typical *Cf* climate. Buenos Aires, for instance, has an almost uniform distribution of rain throughout the whole year. Farther toward the interior, however, the rainfall becomes more and more concentrated in the summer months. Over a forty-year period, Córdoba received during December, her rainiest month, almost twenty times as much rain as during July, her driest month. The city is thus well within the *Cw* climate, while farther west, beyond the Sierra de Córdoba, with increasing aridity, the region comes under the régime of a typical *B* climate.

The decrease of rainfall toward the interior of the Argentine plains is associated with an increasing intensity of precipitation and with decreased frequency of rains in the same direction. The extreme east of the Pampa has an average of 96 rainy days each year; the western Pampa only 60, and in the interior plains (San Juan) the average is as little as 12 (fig. 2). Hail storms are frequent in the interior plains but not in the Pampa.

The prairies of the Argentine are largely located well within the *Cf* climate of which Köppen[5] says: "it produces luxuriant forests of

[5] Köppen, W., *op. cit.,* p. 157.

high trees, wherever tree growth is not restricted by excessive winds or adverse soil condition." Only in the extreme west of the Pampa does the *Cw* climate appear, and the *BS* climate is developed only in the interior plains far beyond the borders of the Pampa.

Vegetation: the monte.—Two strikingly different plant associations exist on the Argentine plains. Conspicuously predominant in the west is the *monte* of native terminology. It is identical with the

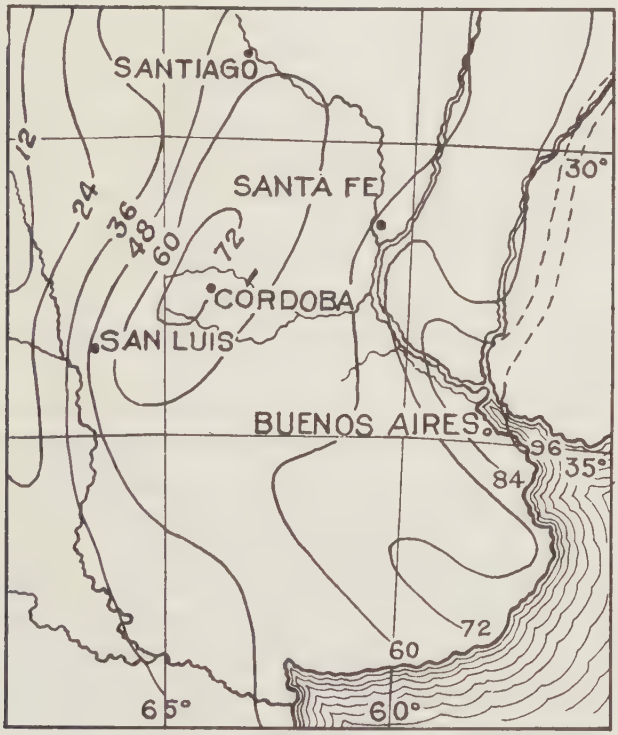

Fig. 2. Annual number of days of rain (after W. G. Davis).

Espinalregion of Hieronymus and with the *Chañarsteppe* of Grisebach,[6] so named after one of its characteristic trees, the *chañar* (*Gourliea decorticans,* Leguminosae), especially common in the extreme west and northwest.

The monte represents a plant association of broad-leafed sclerophyll scrub and trees, the arid winter of the interior plains and the great intensity of precipitation having imposed a strikingly xerophytic character. The monte in its most luxuriant growth is a

[6] Grisebach, A., Die Vegetationsverhältnisse der Erde, vol. 2, p. 429.

tree steppe, called *monte alto* by the natives, and is characterized by trees of 8–10 meters, in rare cases even higher. This monte alto is evidently a climax formation in harmony with the soil and climate of the interior plains which do not permit a more luxuriant tree growth. Even planted trees of mesophytic character refuse to grow in the monte region without artificial irrigation.

Contrasted with the monte alto in which trees predominate is the scrub, *monte bajo*. There is no floristic difference between the monte alto and the monte bajo. The same species which appear in the first as trees are reduced in the second to bushy growths.

Both monte alto and monte bajo have suffered notable loss of area with the expansion of agriculture, but especially has the former been intensively transformed by human culture far beyond the present agricultural limits. Wood consumption in the Argentine is comparatively great because of the expense of imported coal and oil. The best developed trees of the monte alto have therefore yielded before the ax of the *obrajero,* the Argentine wood-cutter. Only the useless scrub is left, and the transformation of the monte alto into the monte bajo is thereby consummated. Around Córdoba, located in the very center of the Argentine monte, one may commonly see an isolated tree, taller by several meters than the surrounding monte bajo, a last indicator of a former higher growing plant association. Thus we can often recognize the monte bajo as a secondary plant association originating in the transformation of a monte alto at the hand of man.

But the monte bajo exists also as a primary climax vegetation, especially in the northwest and westernmost parts of the plains where the increasing aridity makes tree growth of any kind impossible. It is perplexing and frequently impossible to decide in each case whether the monte bajo should be considered as a primary climax unit or as a cultural alteration of the monte alto.

The origin of the open grass-land which appears here and there in the monte region also presents difficulty. In the Pampa de Pocho, an extensive prairie west of the Sierra de Córdoba, a day's ride through "virgin" high grass-land disclosed only a single tree typical of the monte (pl. 30*a*). At the border of this extensive prairie the monte alto as well as the monte bajo is found. The monte in immediate contact with the grass-land is in small groves, but farther on passes into continuous forest (pl. 30*b*). No climatic differentiation, no change in soil material, nor in humidity can explain the existence of this grass-land in the midst of the monte; on the contrary, some

isolated trees prove that the natural conditions do admit tree growth. The grass-land is then not a climax formation but represents a secondary invasion into the xerophytic forest.

The explanation for the existence of these isolated prairies is probably to be found, not in natural conditions, but in the influence of man. The reduction of the monte alto to monte bajo by wood-cutting is widespread. Not a single instance, however, is known where such destruction of the monte by ax has been followed by grass formations.

The grass-land.—East and south of a line which runs from Santa Fé WSW into the eastern province of Córdoba, and from there SSE to Bahia Blanca (fig. 1), the monte ceases to be the predominant plant association and gives way to what was the grass-land of the Argentine Pampa before cultivation almost completely destroyed the earlier vegetation. The Pampa is usually represented as originally entirely wanting in tree growth. There still exist in the Pampa areas of wild range lands. The composition varies locally, the natives distinguishing between the special types of Pampa: *pasto duro,* in which grasses of the genus *Stipa* predominate; *pasto blando,* soft grasses and herbs, now largely of European origin; and *pasto agrio,* mostly sour reed-grass on swampy soils, combined often with the conspicuous high pampa grass (*Cortaderia argentea*).

The first Europeans who penetrated into this landscape were much impressed by the existence of this treeless open country, as shown in the first description of the Pampa left by the few survivors of the expedition.[7] Later on, when the Pampa was made the subject of more exact studies, attention was always attracted by the fact that the eastern plains with their greater humidity produced extensive prairies, whereas the trees of the monte grew on the more arid interior plains. It has always been taken for granted, and has indeed become a kind of dogma, that the grass-land of the Argentine Pampa forms a primary climax unit. Kurtz[8] doubts the influence of atmospheric conditions on the areal distribution of Pampa and monte, arguing that planted trees grow easily in the grass-land. He assumes that the distribution of the underground water determines the distribution of

[7] Report of Capt. Melchor, Palmero and several others of the expedition of P. de Mendoza (1535) *in* Gonzalo Fernandez Oviedo y Valdés (1557) Historia general y natural de las Indias (Madrid, 1851–1855), libr. xxiii, cap. 6, p. 183: "Todo lo que vieron estos chripstianos . . . fue hasta treynta e cinco leguas, poco mas o menos la tierra adentro, la cual era esteril e llana e sin arboles, excepto en las costas de los rios."

[8] Kurtz, F., *in* M. E. Rio y Luis Achával, Geografía de la Prov. de Córdoba (Buenos Aires, 1904), vol. 1, p. 271.

plant formations. But tree plantations by their success everywhere in the Pampa refute this argument, as they do that of control by atmospheric conditions. Seckt[9] tried to explain the existence of the Argentine plains as the result of a "grass-land climate." Lorentz[10] remarked upon the fact that the arid interior produced forest in contrast to the treeless vegetation of the moister Pampa. Grisebach[11] recognized the soil as highly fertile and agreed with Darwin that the climate itself would favor tree growth if it were not for the frequent and strong winds. This statement is evidently inconsistent with the existence of numerous planted trees and groves which have developed normally and show no stunting of growth.

That natural conditions control the existence and extent of the Pampa has remained a premise, assumed but not critically inspected, for no one has ever placed this assumption on an observational basis. Köppen[12] declared that "the striking lack of forests in the Pampa harmonizes pretty well with the small number of rainy days, but is inconsistent with the great amount of rainfall."

However, not even this partial harmony between climate and vegetation which Köppen claims for the Pampa is borne out by the climatologic data. Figure 1 shows a general increase of moisture from the monte region of the interior through the grass-land of the east. It is not only the annual amount of rainfall which increases from west to east, but also the frequency of the rains (number of days with rainfall) and the average relative humidity. Winter, a pronounced arid season in the interior, becomes increasingly humid eastward, Buenos Aires having an almost uniform distribution of rainfall over the whole year. There is then nothing like an effective climatic borderline to explain the areal extent of monte and prairie. Central Texas provides a rather close parallel to the Pampean climate. It should be noted, again, that there is no change of soil character in the critical area of transition between the two vegetational formations. The underlying material of both monte and Pampa is the "Formación pampeana."

In the process of adjustment to these natural conditions one would expect a priori the development of the xerophytic monte toward the

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[9] Seckt, Hans, Die Vegetationsverhältnisse der argentinischen Republik, Zeitschrift des deutschen Wissenschaftlichen Vereins (Buenos Aires, 1918), p. 23.

[10] Lorentz, P. G., *in* R. Napp, Die Argentinische Republik (Buenos Aires, 1876), p. 102.

[11] Grisebach, *op. cit.*, vol. 2, p. 449.

[12] Köppen, *op. cit.*, p. 212.

east into a more mesothermal forest association. The *Cfb* climate has been called by Köppen "beech climate." The appearance of extensive prairies instead is indeed contrary to all experience of vegetational adjustment to climate.

The hypothesis that the existence and extent of the Pampa prairie are not controlled by climate becomes more convincing from further observations. The behavior of many trees, imported as well as native, which grow easily wherever they are planted in the Pampa, proves that the area has not at all a "grass-land climate" hostile to tree growth.

A native tree, the *ombú* (*Phytolacea dioica*), which belongs to the monte formations was planted in great numbers in the early Pampa settlements and has prospered extensively. It has become thus a prominent feature in the grass-land, in fact inseparable from it for the inhabitants. It has no economic value; its wood is very soft and cannot be used even for firewood, since it decays instead of becoming seasoned. Before other trees were imported the ombú was the only tree on the Pampa which gave shade to man, horse, and cattle. All social life took place in its shadow, and even today Argentine national poetry surrounds the ombú with a special nimbus.[13]

Later on other trees were imported, such as the Italian poplar, eucalyptus, the peach tree, and many others which grew very well under the soil and climatic conditions of the Pampa.

The assumption that the Pampa formation is a primary climax formation becomes increasingly untenable when we learn that planted trees not only grow on these plains, but that they formerly sustained here and there tree growth which was not restricted to gallery forests along the streams. We know that more or less extensive groves and forests of monte type occurred almost as far east as the easternmost part of the Atlantic coast. The Pampean mountains such as the Sierra de la Ventana, Sierra del Volcán, and the Sierra del Tandil are still covered by genuine monte. Early observers also give descriptions sufficiently exact to convey an impression of the character and extent of primary tree growth on these plains. A municipal ordinance of Buenos Aires in 1590 prohibits the cutting of algarrobos and other monte trees

[13] Cada comarca en la tierra
Tiene su rasgo prominente
Brazil tiene su sol ardiente
Minas del Plata el Perú
Buenos Ayres—Patria hermosa—
Tiene su Pampa grandiosa;
La Pampa tiene el Ombú.

which grew at the border of the town and gave shelter to the cattle.[14] Another, dated 1608, imposes a certain duty on boats calling at Buenos Aires for wood. The same document complains that the monte in the neighborhood of the town has been largely destroyed by wood-cutters.[15] Falkner[16] mentioned in the later eighteenth century not only the forests along the Rio Saladillo where the *tala* (*Celtis tala*), a typical monte tree, prevails, but describes three other forests, one of them called the Monte del Tordillo near the present Dolores. *Tala*, *coronillo* (*Scutia buxifolia*), and *espinillo* (*Acacia cavenia*), all true monte trees, grow widely in those forests. The name monte is applied to the larger groves; the smaller ones are called *isletas* since they appear like islands in the prairie.

In another paper,[17] Falkner described the isolated but extensive forests north of the Laguna Guamini. The great number of algarrobos (*Prosopis alba* and *P. nigra*), typical monte trees, which these forests

[14] Acuerdos del extinguido cabildo de Buenos Aires, vol. 1, p. 73. 2 de Julio de 1590: "en el exido desta ciudad hazia el Riachuelo de los navios ay algunos algarrobos chicos y los van cortanto algunos vezinos desta ciudad y no los dexan criar . . . no se corten los dichos espinos ny otro genero de monte por causa que es abrigo del ganado vacuno."

[15] *Ibid.*, vol. 2, p. 40: 'los navios que bienen a este puerto y la leña que sacan y han sacado y gastado y que tienen destruido los montes de los terminos desta ciudad."

[16] Falkner, Thomas (1707–1784), A description of Patagonia and the adjoining parts of South America, 1774. Span. ed. *in* Biblioteca Centenaria de la Universidad de La Plata (Buenos Aires, 1911), p. 60: 'En las margenes del rio Saladillo hasta las ocho leguas de su desembocadura crece un árbol que alli llaman tala, que solo sirve para leña y para cercos. El último de estos montes que se llama Isla Larga, llega hasta las tres leguas antes de la desembocadura en el rio de la Plata." P. 68: "Al sur del pueblo de la Concepción en la banda austral del rio de la Plata está el cerro de la Víboras, y alli se divisan dos bosques redondos, muy tupidos, separados por un espacio. Unas cuatro leguas al sur de éste está el Monte de Tordillo, que consta de muchas islas de monte de mayor ó menor extensión. Los árboles son los mismos que se ven en los bosques del Saladillo. Algunos de estos bosques se acercan hasta dos leguas de la costa del mar." Pp. 71–72: "Al este del Vuulcan hacia el océano el campo es accidentado por 2 leguas; después corre llano, . . . hay algunos bosques espesos y hasta casi impenetrables . . . abundan los saúcos que aquí alcanzan mucho cuerpo y se elevan a 6 y 7 yardas." (Saúco = Sambuciis australis.)

[17] Falkner, P. Tomás, Derrotero desde la ciudad de Buenos Aires hasta la de los Césares que por otro nombre llaman la ciudad encantada, 1760. *In* P. de Angelis, Colección de obras y documentos relativos a la historia del Rio de la Plata (Buenos Aires, 1836), vol. 1, part 4, pp. 22–23: "En la laguna de Guamini suelen juntarse hasta 600–800 indios Pampas y solamente en el tiempo de cosecha de la algarroba para . . . entrar con tiempo al monte, que dista de allí como cosa de cuatro leguas poco mas; en cuyo monte hay mucha cantidad de algarroba, de donde se proveen para su mantenimiento, y para hacer la chicha para todo el año.

"Desde este laguna hasta pasar á la otra parte del monte, hay de travesía, por una parte, setenta leguas, en parte mas, y en parte menos; con la advertencia que en medio de este monte habitan otros indios llamados Mayuluches, y serán como 4–5000 todos. Saliendo de este monte tirando siempre hacia el poniente, se pasa por unas campañas cuya travesía es de 30 leguas . . . donde apenas se encuentra tal cual árbol."

contained, attracted each year a large number of Pampa Indians who came to collect the ripe fruits of the trees, which they used as food and in the preparation of beer.

Concolorcorvo, who, twice in the eighteenth century, made the journey from Peru to Buenos Aires, reports another forest not far west of Buenos Aires. According to him there was a *tala* forest two *leguas* wide near the highway from Buenos Aires to Luján, from which the owner and his family made their living by selling lumber to the people of the city.[18]

But we do not need to go back to early historic sources to find sufficient evidences of the original penetration of the monte formation into the grass-land of the Pampa. The monte of the Pampean mountains has already been mentioned. In the steep gullies (*barrancas*) near Buenos Aires are numerous endemic representatives of the monte formation. These barrancas evidently form places in which parts of the original vegetation found shelter from the invasion of man. The *espinillo* grows in the barrancas of San Isidro and near La Plata, the *sombra del toro* (*Jodinia rhombifolia*) at Los Talas, the *molle* or *incienso* (*Schinus dependens*) along the banks of the Rio de la Plata and all the streams of the province of Buenos Aires. But especially is the *tala* still to be found in numerous groves around the city of Buenos Aires and in the barrancas of Flores, San Isidro, Quilmes, etc.[19]

All these relics of an original monte tree growth in the very heart of the present grass-land give sufficient reason to doubt seriously the thesis that the Argentine Pampa has a "grass-land climate," and that its extensive prairies, as the Spaniards found them, are a natural climax formation. On the contrary, a striking contrast exists between the natural conditions, which are quite favorable to tree growth, and the actual existence of very extensive prairies. Since natural conditions did not convert the original tree growth to a grass-land, there remains only the assumption that the primary monte yielded under the influence of some biotic factor.

Our knowledge of human life in the Pampa in pre-Columbian times is very restricted, but according to early testimony the Spaniards

[18] Concolorcorvo, El lazarillo de ciegos caminantes desde Buenos Aires hasta Lima 1773. Edition of the Junta de Historia y Numismática Americana (Buenos Aires, 1908), pp. 46–47. It is evidently the same forest mentioned as Monte de Castro, two and a half *leguas* from Buenos Aires on the road to Luján, by José Santiago Cerro y Zamudio, Itinerario de un nuevo camino desde le ciudad de Buenos Aires hasta la de San Augustin de Talca, capital de la provincia de Maule, en Chile, 1805, *in* P. de Angelis, *op. cit.*, vol. 1, part 7, p. 11.

[19] Hicken, Cristobal M., Chloris Platensis Argentina (Buenos Aires, 1919).

found the banks of the Rio de la Plata densely settled. As soon as the discoverer of the Rio de la Plata, Juan Díaz de Solis, disembarked with fifty men, they were attacked by a great number of Indians and none of the Europeans escaped. The Indians must indeed have been very numerous, for the rest of the Spaniards, witnessing the scene from their ships, were so impressed by the number of their enemies that they did not dare go on shore, but returned to Spain without further attempt to disembark.[20] The fort which Sebastian Gaboto founded in 1526 at the northern border of the Pampa near the Rio Carcarañá was taken and destroyed by an army of more than 20,000 Indians.[21]

In 1535, when Pedro de Mendoza founded the town of Buenos Aires for the first time, there stood near the new settlement a village inhabited by about 2,000 Querandí Indians.[22] These Querandí received reinforcements of 4,000 warriors from their friends, in alliance with whom they soon gave battle to the Spaniards.[23] In the same year an army of about 23,000 Indians, belonging to four different tribes, attacked the Spaniards at Buenos Aires.[24]

The tribe of the Timbos, whom the Spaniards found in the northern Pampa on the banks of the Paraná, were estimated at 15,000.[25] As late as 1876, after they had suffered the consequences of over three hundred years of warfare with the Spaniards, Major Melchert estimated the number of the nomadic Indians of the Pampa at 24,000.[26]

Supposing even that the first explorers exaggerated the number of the Indians, there is little doubt that the Pampa along the southern shores of the Rio de la Plata and the western banks of the Paraná supported a dense population according to conditions prevalent in aboriginal America. The military resistance of these people to Spanish invasion at the time of Spain's greatest military vigor, not by guerilla warfare, but promptly and directly by battle, again suggests an active and numerous people. There exists, therefore, at least the possibility that this pre-Columbian population had already produced far-reaching changes in the original vegetation when the Spaniards first saw the country.

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[20] Oviedo y Valdés, *op. cit.*, libr. xxiii, cap. 1.

[21] Oviedo y Valdés, *op. cit.*, libr. xxiii, cap. 3.

[22] Ulrich Schmidels Reise nach Süd-Amerika in den Jahren 1534–1554 nach der Münchner Handschrift. Tübingen 1889, p. 28.

[23] Schmidel, U., *op. cit.*, p. 29.

[24] Schmidel, U., *op. cit.*, p. 32.

[25] Schmidel, U., *op. cit.*, p. 34.

[26] Major Melchert *in* R. Napp, *op. cit.*, p. 427.

All early chroniclers agree that the Indians of the Pampa knew no agriculture whatever.[27-30] They lived exclusively on hunting and fishing. Mendoza's troops which took the great village of the Querandí near Buenos Aires in order to provide themselves with fresh food, found nothing but furs and fish.[31] These Pampa Indians lived a roving life, pitching their skin tents wherever they found convenient hunting grounds. It is therefore out of the question that the pre-Columbian Indians might have cleared away the original monte to get lumber for their houses and space for their fields. Yet they may have destroyed the primary tree growth even more thoroughly in still another way.

There are a great number of records which prove that the Pampa dwellers handled fire effectively and for definite purposes. Evidence of such practice among the pre-Columbian aborigines is possibly represented by the so-called *tierras cocidas* in the loess of the Pampa formation. These *tierras cocidas,* often found in the Argentine plains, consist essentially of a brick-like material. Its genesis has been much discussed,[32-38] but it is a significant coincidence that such material appears to have originated *in situ* where the luxuriant

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27 Martin del Barco Centenera, Argentina y Conquista del Rio de la Plata (Lisboa, 1602), cant. 11, p. 16 *in* Biblioteca de la Junta de Historia y Numismática (Buenos Aires, 1912), vol. 5: "Los Guaranís son solo labradores. Los mas dados a caça y pescadores."

28 Oviedo y Valdés, *op. cit.*, libr. xxiii, cap. 3.

29 Schuller, R. R., *in* Prólogo a la geografía física y esférica de las provincias, del Paraguay por Felix de Azara, Anales de Museo Nacional de Montevideo, Sección histórico-filosófica (Montevideo, 1904), p. cv.

30 Carta de H. de Montalvo, containing a description of the rio de la Plata, 1576. Archivo General de las Indias, Documentos relativos al rio de la Plata *in* Anales de la Biblioteca (Buenos Aires, 1915), vol. 10, p. 100, calls the Charrúas "gente gandul que no siembran . . . manteniendose de pescados y venados y abestruces."

31 Schmidel U., *op. cit*, p. 29.

32 Steinmann, G., Sur les scories intercalées dans la formation pampéenne inférieure, Revista del Museo de la Plata, vol. 15 (1907), pp. 461–62.

33 Ducloux, E. Herrero, Estudio químico de las "escorias" y "tierras cocidas," Revista del Museo de la Plata, vol. 15 (1908), pp. 162–67.

34 Bücking H., Estudio microscópico de las "escorias" y "tierras cocidas" Revista del Museo de la Plata, vol 15 (1908), pp. 185–87.

35 Ameghino, F., Productos píricos de origen antrópico en las formaciones neógenas de la República Argentina, Anales del Museo Nacional de Buenos Aires, ser. 3, vol. 12 (1909), pp. 1–25.

36 Outes, F. F., Les scories volcaniques et les tufs éruptifs de la série pampéenne de la République Argentine, Revista del Museo de la Plata, vol. 16 (1909), pp. 34–36.

37 Frenguelli, J., y Outes, F. F., Posición estratigráfica y antigüedad relativa de los restos de industria humana hallados en Miramar, Physis. Revista de la Sociedad Argentina de ciencias naturales, vol. 7 (1924), pp. 277–398.

38 Ameghino, F., Examen critique d mémoire de M. Outes sur les scories et les terres cuites, Anales del Museo Nacional de Buenos Aires, ser. 3, vol. 12 (1909), pp. 459–512.

Argentine grass (*Cortaderia argentea*) is known to have been burned. Fl. Ameghino cites instances of travelers burning *cortaderales* to open their way; of landed proprietors to clear land, and of Indians doing the same for hunting purposes.[39] The cortaderales fires often continue for days in the soil, where the roots undergo a slow process of combustion. Ameghino also cites a number of concrete instances in which such fires actually produced a material identical to the *tierra cocida* that occurs in the upper layer of the Pampa formation. It is therefore well within the range of probability that the *tierras cocidas* of the Pampa form traces of man's destruction of the original vegetation by fire.

The first chronicler of the Rio de la Plata recounts the skill with which the Indians used fire in attacking their enemies. When besieging Buenos Aires they set fire to the houses of the Spaniards with fire-arrows and burnt thus not only the whole settlement but also four ships.[40]

Since Schmidel's time almost every report on the Pampa, prior to the agricultural conquest of the eastern plains, makes some reference to the burning of the grass-land. Tschudi thus describes the superior tactics of the Indians when fighting against troops of European equipment. With a single prairie fire they could endanger the slow-moving infantry and artillery.[41] Major Melchert makes the same statement and emphasizes the ability of the Pampa Indian to use steppe fire in his own defense.[42]

Sarmiento[43] related how the gaucho, descendant of Indian and Spaniard, with the customs of the former, sought safety by setting back-fires when the Pampa was ablaze, and Hudson[44] has given a most vivid picture of the constant fear of prairie fires in which the stock-raisers of the Pampa lived during the dry weather.

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[39] Ameghino, F., Dos documentos testimoniales á propósito de las escorias producidas por la combustión de los cortaderales, Anales del Museo Nacional de Buenos Aires, vol. 12 (1909), pp. 71–80.

[40] Schmidel, *op. cit.*, pp. 32–33: "etliche lieffen den sturm, die anderen schoossen mit feirigen pfeilen hinein auf unsere heuser, welche mit stroh geteckht unnd verprenten also unnser stat in grundt. Dazu verprenten sie unnss auch 4 grosse schieff, welche auf ein halbe meil vonn unss auf dem wasser stunden."

[41] Tschudi, J. J. von., Reisen durch Südamerika (Leipzig, 1868), vol. 4, p. 253.

[42] Major Melchert *in* Napp, *op. cit.*, p. 429.

[43] Sarmiento, Domingo F. (1811–1888), Facundo, civilización y barbarie en la República Argentina (Madrid, no date), p. 43.

[44] Hudson, W. H., Far away and long ago. A history of my early life (New York, 1924), pp. 68–70.

Darwin[45] found fine but hazy weather on his way through the Pampa from Bahia Blanca to Buenos Aires in 1833. The gauchos told him that the plains were on fire at some distance in the interior. He says farther on: "When riding through the country, it is a common practice to set fire to the plain; and hence at night, as on this occasion, the horizon was illuminated in several places by brilliant conflagrations. This is done chiefly for improving the pasture."

Azara, the best authority on the La Plata area during the colonial period, makes a most significant statement regarding the existence of a well established custom of burning the Pampa at regular intervals. According to him, the Pampa dwellers used to set fire to the vegetation as soon as it became dry. He says that this was done to obtain fresh sprouts as feed for the cattle. Such prairie fires spread with the wind and stopped only where a creek or a road formed an insurmountable obstacle. Azara cites the fact that he himself rode south of Buenos Aires for more than 200 leagues over Pampa which had recently been swept by a single fire and was just beginning to sprout again.[46]

Since it is a general experience that fires are especially destructive to trees and shrubs, promoting thus the dominance of grass, it is at least well in the range of possibility that the grass-land of the Pampa, as the Spaniards found it, owed its origin mainly to the interaction between man and his habitat. The fact that the same invasion of the grass into the monte was less successful in the western part of the plains is therefore easily understood. The dwelling places of the aboriginal population were concentrated along the eastern border of the Pampa where they found permanent water. From there they went westward to hunt the guanaco, deer, and ostrich. Thus the far western part of the plains was out of range of the influence of a comparatively numerous population of hunters, who had the same interest in the expansion of the grass-land at the expense of the monte, that was shown later on, in Spanish colonial times, by the stock-raising gauchos.

We arrive thus at the conclusion that the Spaniards found the Argentine plains covered in the west by a climax formation, the monte, whereas the eastern plains, the Pampa proper, probably represented at that time a cultural landscape, bearing the signs of an intensive transformation originated by the pre-Columbian population.

[45] Darwin, Charles, Journal of researches into the natural history and geology of the countries visited during the voyage of H.M.S. Beagle round the world (new ed., London, 1852), pp. 106, 114.

[46] Azara, Felix de, Descripción é historia del Paraguay y del rio de la Plata (Madrid, 1847), vol. 1, p. 56.

EXPLANATION OF PLATE

PLATE 30

a. An isolated *monte* tree in the grass-land (Pampa de Pocho, Prov. de Córdoba).

b. Border between *monte* and grass-land (Pampa de Pocho, Prov. de Córdoba).

a

b

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LOWER CALIFORNIAN STUDIES. I. SITE AND CULTURE AT SAN FERNANDO DE VELICATÁ

BY

CARL SAUER AND PEVERIL MEIGS

The ruins of the Mission San Fernando de Velicatá lie approximately on the 30th parallel, three hundred miles by road below the American border. For a while this was a critical and distinctive site in the northward expansion of European culture along the Pacific. The present study is concerned with the characteristics of this particular locality and with its fortunes. The area forms a small geographic unit and at the same time a link in the major cultural succession.[1]

AT THE LIMIT OF THE SONORAN DESERT

The greater part of Lower California belongs to the Sonoran Desert, the Gulf of California having no influence on the prevailing aridity, except for infrequent fogs. South of San Fernando, the land is virtually uninhabited at present as far as San Ignacio and Santa Rosalia, a distance of 275 miles by road (fig. 1). To this desert section the name of its most important culture center, that of San Borja, is here applied. Though long since completely ruined, it remains still the most significant feature that man ever established within this extremely arid stretch.[2] Still farther south there is a

[1] The observations included in this paper were made by a party from the University of California, May, 1926, including, in addition to the authors, F. Kniffen and S. Dicken.

[2] Nelson named the district the "Vizcaíno Desert" (Nat. Acad. Sci. Memoirs, vol. 16 [1922], p. 12). We prefer not to use the name which is taken from the Bay of Sebastian Vizcaíno on the west coast, because that bay is not in as typical desert country as the interior, and did not participate in the developmental history of the area; and because the name, in the shortened form used, means literally the Biscayan Desert.

feeble development of savanna climate, with local areas of moderate rainfall caused by isolated mountain masses (the Cape District of Nelson). The head of the Gulf and its western coast as far south as the latitude of San Fernando are in the Colorado Desert, also belonging to the greater Sonoran region, and in the main a sandy lowland.

San Fernando lies almost at the northern limit of the San Borja Desert. Its uncertain rains may come, desert fashion, as summer thunderstorms, or, by a fleeting invasion of winter cyclones from the land to the north, as longer rainy spells in winter. The average amount of rain is probably not more than five inches a year, as indicated by informal rainfall records at Onyx. Occasionally there are years without rain. The Jesuit Link claimed that he spent seven years at San Borja, 160 miles to the south of San Fernando, without having any rain.[3] No modern drought of such length is known however. At San Fernando there are now and then high fogs that drift in from the ocean at night, especially in summer. The Pacific slopes are relieved even more by sea fogs. A height of land lying about midway between San Fernando and Rosario, the latter a coast village, and extending thence northward to the central sierras, may be taken as the precise northwestern limit of the San Borja Desert (fig. 1).

From Rosario northward beyond San Diego, desert rainfall values persist along the coast, but relatively low temperatures, low diurnal range, and strikingly low evaporation, largely due to the prevalent fog bank along the coast, reduce the severity of the dryness. This delightfully equable San Diegan Desert (*BWn* of Köppen) is not considered locally as desert at all and indeed has a moderately dense cover of vegetation and supports dry-farming, though the rainfall is only from five to ten inches. With increasing elevation inland, hot steppe (*BSh*) and mesothermal conditions (*Csa*) are developed behind this coast. The Dominican Sales[4] classified the coastal missions north of San Fernando as of *temperamento húmedo y frío,* San Fernando and those to the south as *cálido y seco.* To the sun-scorched padres who had just completed the terrible desert trail north from San Ignacio, the coast and mountains beyond San Fernando were a land of grateful coolness and even of moisture.

[3] Murr, C. G., Nachrichten v. verschied. Ländern d. span. Amerika (1809–11), p. 405.

[4] Noticias de la Prov. de California (Valencia, 1794).

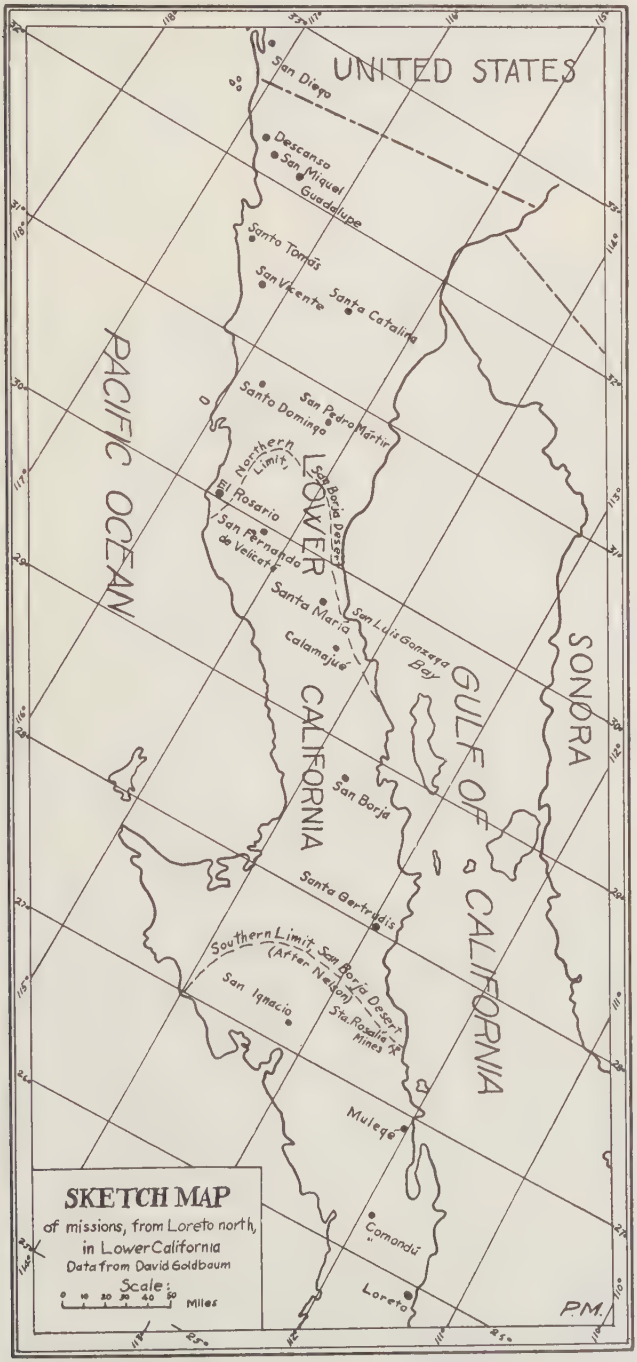
UNITED STATES
San Diego
Descanso
San Miguel
Guadalupe
Santo Tomás
San Vicente
Santa Catalina
Santo Domingo
San Pedro Mártir
Northern Limit
El Rosario
San Fernando de Velicatá
Santa María
San Luis Gonzaga Bay
Calamajué
San Borja
Santa Gertrudis
Southern Limit San Borja Desert (After Nelson)
San Ignacio
Sta. Rosalía Mines
Mulegé
Comondú
Loreto
P.M.
PACIFIC OCEAN
LOWER CALIFORNIA
GULF OF CALIFORNIA
SONORA
SKETCH MAP
of missions, from Loreto north, in Lower California
Data from David Goldbaum
Scale:
0 10 20 30 40 50 Miles

Fig. 1

About San Fernando the vegetation, though of desert character, is abundant, there being few places on plain or mesa where a number of plants are not found on every square rod of ground. Herbaceous plants are least conspicuous and least numerous, except in the beds of the arroyos and about the water holes. The flora is typically Lower Sonoran. Woody, thorny brush, very stunted, and growing at best waist-high, is especially abundant. This assemblage is commonly known as *chamiso*, in particular those elements of it that are useful as forage and for their seeds (pl. 31*a*).[5]

The landscape is dominated by the larger growths, especially cacti, maguey, and ocotillos. Most impressive are the giant *cardones* (*Pachycereus*), which are so abundant on and between the arroyos of Rosario and San Fernando as to give rise to cactus forests, or *cardonales*. At the mission they form the background of the stony southern hillslope (pl. 33*b*). Of lesser stature but far greater abundance is the notorious *cholla* cactus (*Opuntia cholla*), which detaches its spiny segments at the lightest contact (pl. 32*a*). Cacti of the *pitajaya* and *viznaga* varieties are not common locally, and may have been reduced by exploitation, though this is only surmise. The maguey (*agave*) of the locality (pl. 31*a*) is a much smaller variety than are those of the west coast. Its curiously uneven stand may also be the result of depredations upon it because of its former high significance as food. Eastward the common ocotillo, with spiny whip-like branches (pl. 31*a*), is very abundant. San Fernando lies in the belt of the ghostly forest of *cirio* (*Idria columnaris*) (pl. 31*b*). This strange tree, with its extremely stunted branches and thick, pulpy stems, light green and tapering, is very common about the mission and occurs only in this section of the peninsula. Cirios are found on both mountain slope and plain in the San Fernando locality and occur westward as far as the upper Rosario Valley, usually in mixed stands with cardones (pl. 32*b*). Local information places the northern limit of their distribution in the upper Arroyo San Simon, a hill country about forty miles north of Rosario. Their development is therefore nearly restricted to the San Borja Desert and is greatest in its western portion.

The arroyos are more or less overgrown by thickets of mesquite. This condition is similar to that in the Colorado Desert and in contrast to the arroyo vegetation of the coast section north of San Fernando.

[5] Goldman, E. A., Contrib. U. S. Nat. Mus., vol. 16, pt. 14 (1916), identifies from this area in particular species of *Atriplex, Covillea, Simmondsia,* and *Prosopis.*

The arroyos also contain reedy growth on their floors in so far as these have not been washed out. In spring, moreover, they are gay with brightly flowering annuals. The cirio, cardon, dwarf agave, and mesquite in particular serve to distinguish the local plant assemblage from those in the less arid regions to the north.

THE LLANOS DE BUENOS AIRES

San Fernando lies at the western margin of the Llanos de Buenos Aires (fig. 2), a table-land obscurely known as to limits and in the main obscurely defined. The table-land extends in general from the base of the northern sierras southward for about fifty miles, to the vicinity of Cataviña, and occupies the central part of the peninsula. In its southern portion a low and especially smooth plain is developed, which reaches from San Fernando eastward to Onyx, nearly thirty miles in length and for the most part less than ten miles broad. Here are the *llanos* proper, forming an easy and important passageway from east to west across the peninsula.

The mean elevation of the plain is around two thousand feet, San Fernando at its lowest point being about 1,700 feet above sea level, Onyx, at the eastern margin, about 2,300 feet. The plain rises insensibly eastward to some low hills beyond Onyx, from the tops of which one looks out suddenly to the Gulf of California, over a land of very sharp and jagged ridges, falling off sharply to the sea. Now and then Yaquis work dry placers in this district, called Miramar, but only when winter rains provide water is living possible on this barren coast. Northward this great escarpment recedes gradually from the Gulf coast, and continues as the wall-like front of a series of ranges abutting against the Colorado Desert. The western margin of the llanos is also sharply defined by a series of irregular, narrow ridges, here and there surmounted by a conical peak. Their elevation above the plain is perhaps five hundred feet on the average. They have prevalently a northwest-southeast trend, are somewhat sinuously parallel to each other, and are roughly so to the distant Pacific coast. To the west of them a series of broad mesas, deeply trenched by arroyos trending directly toward the sea, provides a descent to the sea by a succession of lower levels. Four topographic regions, therefore, are developed in this part of the peninsula: (1) at the east an extremely rugged and jagged escarpment along the Gulf, (2) in the center the smooth plateau of Buenos Aires sloping gently to the west

from the crest of the escarpment, and cut off (3) by a belt of narrow ridges and basins, five to fifteen miles in width, and (4) along the Pacific a series of mesas ending in a narrow coastal plain.

The Miramar district consists largely of slates, highly deformed. The Buenos Aires plateau has prevalently a base of granite. The ridges to the west are in part formed in highly metamorphosed sediments and igneous rocks, in part underlain by extrusive sheets. High angle faults are topographically conspicuous, and deformed faults are common. The Pacific mesas are composed of nearly horizontal sediments and extrusive materials.

Northward the profile of the peninsula is altered principally by the replacement of table-land through mountain ranges. The Sierra San Pedro Martir, trending somewhat west of north, adjoins the Buenos Aires plateau at the north. Beyond and somewhat overlapping it, is the Sierra Juarez. On the American side the Cuyamaca, Hot Spring, and San Jacinto mountains continue this arrangement of mountain blocks *en échelon*. This pattern of mountain arrangement, varied as to scale, continues to the north apparently to the Tehachapi, but is terminated at the south by the table-land of Buenos Aires. The character of the basal rocks, however, does not appear to change southward. Similar granites appear to underlie the table-land and to compose the cores of the mountain ranges. A tremendously contorted zone of slaty metamorphic rocks is found at the east. Highly deformed and faulted sediments and igneous rocks, as well as a zone of recent volcanic activity, lie to the west of the plateau. These conditions are repeated in the margins of the mountains to the north and suggest tectonic similarity to the Sierra Nevada.[6]

In view of the absence of information about the northern and southern limits of the table-land, the geomorphology of the area cannot be reconstructed, except in most tentative form. The relative monotony of the plateau may indicate rather advanced denudation. The great scarp terminating it at the east, though perhaps an ancient diastrophic zone, assumed its modern form in the breaking down of the Gulf graben and in the main established the present relief. The western rim of the plateau is a zone of much faulting and volcanic activity, in both cases oft repeated and in part recent. Even the flat-lying coastal mesas have many small faults, especially well shown on the coast south of Rosario, most particularly about Punta Baja.

[6] Emmons, S. F., and Merrill, G. P., Geol. Sketch of Lower California, Bull. Geol. Soc. Am., vol. 5 (1894), pp. 489–514; the only structural study concerned with the Buenos Aires sector.

Fig. 2

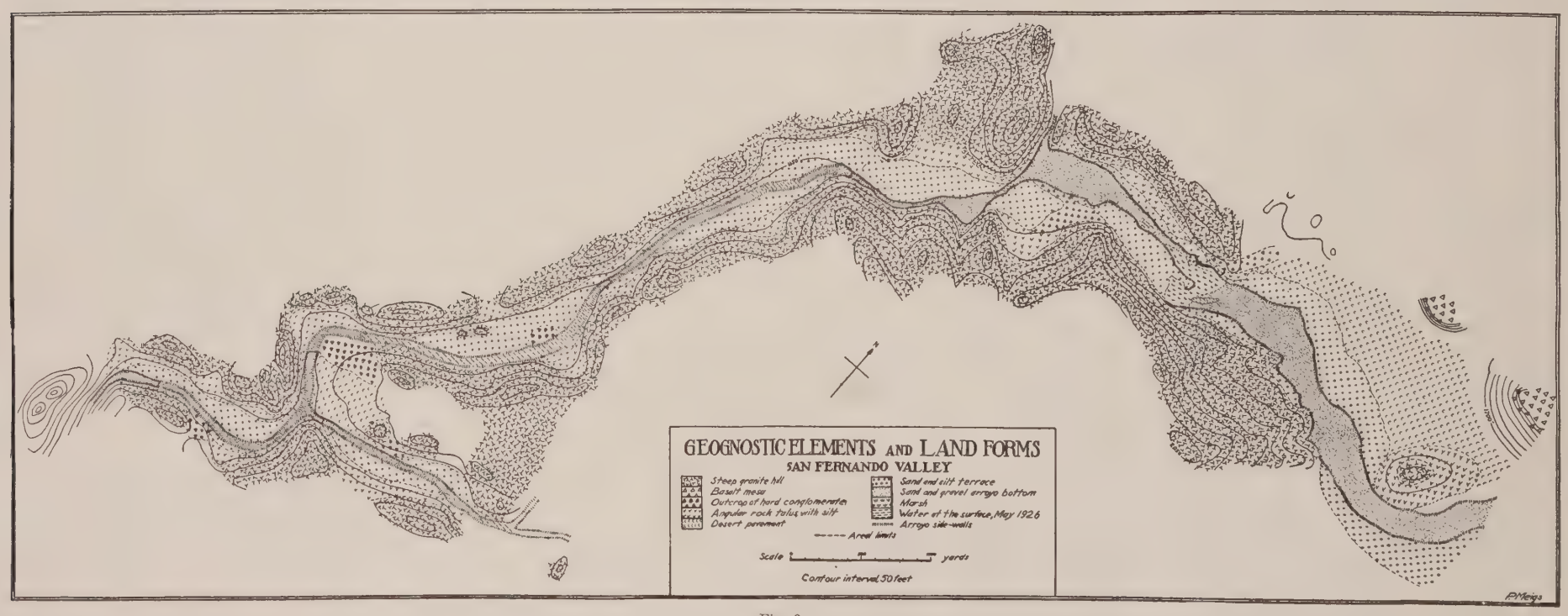

Fig. 3

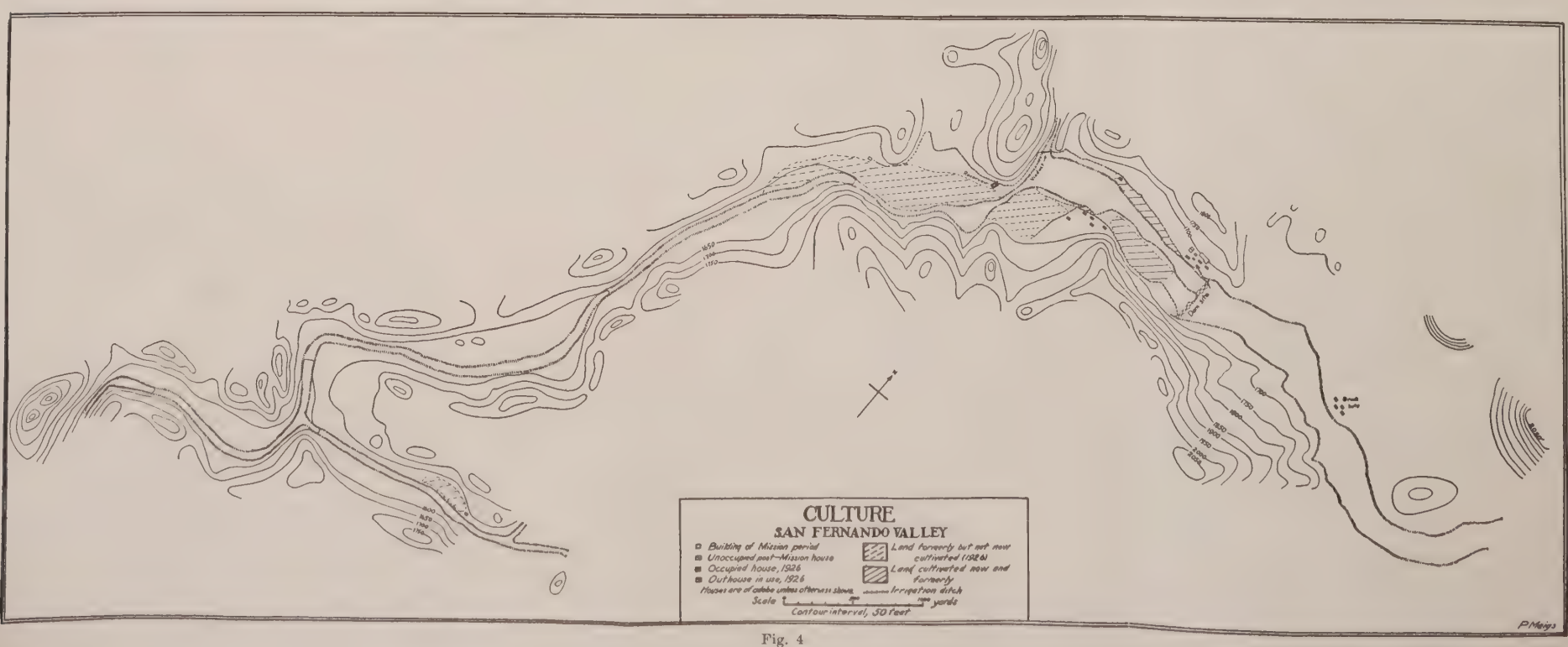

Fig. 4

Some of these faults cut the latest and lowest marine terraces. Recent lavas and tuffs are common at the surface in the western rim and in places on the plateau. Whereas the local area was less raised than the areas to the north by recent diastrophism, it appears to be a diastrophically well-determined block, not more inert than those to the north, but, as will be shown in the following paragraphs, more unstable, and in its present relief, probably younger.

On the Buenos Aires table-land are, thinly spread, recent sedimentary beds and volcanic tuffs. These are usually found in low, strikingly flat-topped mesas scattered over the plain and include in particular "deposits of porous limestones and travertine and coarse conglomerate with calcareous cement containing rounded fragments of both eruptive and sedimentary rocks in great variety and of varying size up to several feet in diameter."[7] Material of this sort is found not only over the plain but it appears, especially the conglomerate, in many patches in the valleys that have been cut in the western metamorphic area, and in numerous cases virtually on the floors of the present valleys. Such material is common in the Arroyo San Fernando. A bed of conglomerate partially blocks the valley floor at the mission and provided the occasion for the dam which the friars built at that place. The valleys of the western rim appear to have existed virtually in their present form prior to a marine inundation which submerged most of the present table-land. The size and marked rounding of the gravels and cobbles and their great surficial extent do not suggest an interior lake, as Emmons and Merrill postulate, but, rather, effective wave action by a tide and storm-swept body of water. These deposits are the record of the first marine transgression, which, rather than desert denudation, may be responsible for the subdued relief of the llanos.

A distinctly later marine submergence is also substantiated by a varied line of evidence: (1) The older mesas of marine materials have lying between them in many places a lower floor, very smooth and covered by silt of medium texture, not distinguishable in appearance from the estuarine deposits forming today along the coast, as at San Quentin. This silt contains numerous fragments of shells. (2) On the outer margins of the table-land, and quite unrelated to possible Indian habitations, are beds of shells, lying at the surface, uncemented, and almost unweathered. Clams and rock-mussels of varieties now living on the coast appear to compose these accumulations. (3) In the

[7] Emmons and Merrill, *op. cit.*, p. 507.

western dividing ridges there are flat-topped surfaces that consist of cobble fields as yet unaffected by weathering. These cobbles are lithologically much more varied than the underlying rocks.

On the rising ground east of Onyx, almost at the crest of the escarpment, shells are strewn about the surface, there being no indication in their appearance, or from the underlying material, that they have weathered out. At the other end of the llanos, on the main road between San Fernando and Rosario, about nineteen miles west of the mission, the road crosses several flat-topped rhyolitic ridges. Here, at an elevation of about two thousand feet, cobble fields may be seen on the ridge tops. The stones are very well rounded, fresh, and abundant. In slight depressions in the cobble-strewn surface masses of shells may be found, also obviously fresh and uncemented. These mesas lie almost at the highest level of the rim immediately to the west of the Buenos Aires plain. It appears, therefore, that the sea very recently reinvaded this area, forming wave-cut terraces and reefs and embayments that extended entirely across the peninsula.

The major relief of the area is determined therefore by faulting, vulcanism, and by marine planation and filling. The large valleys of the west, at least in their upper parts, are ancient, have been involved in marine transgression, and, if stream cut, date back to relief conditions far removed from those now found in the peninsula.

The Buenos Aires surface, above the level of the marine flats, shows subdued slopes of desert weathering, strewn closely with subangular rock fragments, so-called *pedregales*, or desert pavements (pl. 33*a*). The rock exteriors characteristically have altered to blackish-brown, irrespective of lithologic composition, with the one exception of the quartz fragments. The pedregales may be underlain by bedrock or by terrace or mesa materials. They tend to mask, therefore, both soil and lithology of the area.

A basal concentration of salts, especially of lime carbonate, is common in the sedimentary materials of the plain. This so-called *caliche* forms a whitish, floury mass, in many places twenty to fifty feet thick, and partly cements the gravels or other sediment in which it occurs. It may have formed in part by the evaporation of old lagoons. It is, however, so irregularly distributed and of such varying elevation, that it is perhaps best considered as a normal feature of the subsoil in this desert, now forming by subsurface evaporation from a fairly deep water table.[8]

[8] Blake, W. P., Engin. and Min. Jour., vol. 72, pp. 601–2; Min. and Sci. Press, vol. 82, p. 204; Carnegie Inst. Publ. 99, pp. 64–66.

The structure of the table-land gave direction to the expansion of the missions. As a passageway its rôle is obvious. Marginal arroyos in number descend to the central basin especially from the north and are promptly lost beneath the basin floor. A large part of the water that is carried down is absorbed by the porous materials that fill the lower parts of the basin, and moves westward underground to the outlet at San Fernando. The Llanos de Buenos Aires are therefore a desert reservoir of value, providing at the mission site a permanent flow of somewhat alkaline but usable water. Where the water seeps to the surface at the head of the Arroyo San Fernando a reedy marsh developed, whence the site was named by the Indians *Guiricata* (*Huilicata, Velicata*), Spanish *carrizal,* a locality full of reeds.[9]

THE JESUIT RECONNAISSANCE

The Jesuits entered Lower California in 1697 at Loreto. Against the formidable odds of extreme desert conditions and persistently rugged land surfaces they pushed their missions outward steadily so that by 1762 they had brought under their control virtually the entire Indian population south of the Buenos Aires district.[10] In that year they established the Mission San Borja (28° 50′ N), in the very heart of the desert to which we have given its name. Link, in charge at San Borja, stated that in 1767 there remained no unbaptized Indian south of the 31st Parallel.[11] The Jesuit conquest of Lower California ranks with the best of the exploits of that indefatigable order.

The record of the closing stages of Jesuit expansion, involving the local area, is imperfect. Neither the diary of Link, who was in charge of this frontier, nor his *History of the Missions* has been recovered. There is extant, however, a sufficient account, principally through Clavigero's History,[12] to sketch in their northernmost activities. San Ignacio (fig. 1) was the last of their great stone missions, built in the

[9] Negrete, Bol. Soc. Mex. Geog. y Estad., vol. 7 (1859), p. 348.

[10] Baegert, Nachrichten v. d. amerikanischen Halbinsel Californien (1772), gives a shrewd and vigorous account of the peninsula and its occupation by the Jesuits.

[11] Murr, *op. cit.,* p. 405. The latitude as usual is too high, probably by at least a degree.

[12] Francesco Clavigero, whose history was published originally in 1789 in Italian, obviously had access to excellent sources of information, in particular concerning the northern missions. It is a critical and admirable contribution, illustrative of the careful geographic and ethnographic observations that distinguished the Jesuits in most of their missionary fields. The Spanish translation, Historia de la antigua Baja California, is followed in this paper.

proud expectation of permanent tenure. To the north lay the feared *infierno,* a desert and rugged country that marked the lower end of the San Borja Desert. Through it Consag led the first party northward in 1751, intending to seek out farther locations for missions. He got as far as Calamajue and selected the site at which the mission of Santa Gertrudis was founded in 1752. The following year he went north along the Pacific coast, apparently as far as the Arroyo San Fernando, without finding a desirable site. Along this route there has never been a settlement, except briefly at landings that served ephemeral mines. Retz was placed in charge at Santa Gertrudis, and reconnoitered the site of San Borja, first projected as a mission in 1759. A mission was established here in 1762 by Link, who appears to have continued in principal charge of this farthest frontier to the time of the expulsion decreed in 1767. He asserted that "the last mission to the north counted in 1767 more than 5,000 Californians, baptized between 1760 and 1767," claiming for all the missions of the south only 7,500 Indians at the time.[13]

In 1766 Link undertook an exploration to the north. He reexamined the Calamajue site first noted by Consag and then made a detailed reconnaissance of the Llanos de Buenos Aires. From Calamajue they passed "several days through a land less mountainous and rough, but so sterile that there was scarcely water for travelers and beasts. Passing beyond they encountered a region abounding in pasture, with an arroyo and various springs, whose water, though insufficient to irrigate grain-fields, would suffice to support a considerable amount of stock." This place they called San Juan de Dios, the spring, arroyo, and mountain to the northeast of San Fernando still bearing the name. The pasture lands are parts of the llanos. In order that this region "might be useful it was necessary to find at a short distance still another site where the Mission might be planted. This was found four leguas distant, where a copious stream issued, the water whereof could easily irrigate the lands lying on both sides of it."[14] Thus was the place discovered on which San Fernando was to be built. Clavigero continues: "There exists moreover much pine and other species of trees useful for timber, which were lacking in all the other missions of California, excepting the southern ones. This place, situated about the 32d Parallel, is called by the Indians Guiricatá." The pine

[13] Murr, *op. cit.,* p. 406; Ducrue, *in* Murr, *op. cit.,* p. 417, credited Link with the baptism of nearly two thousand Indians.

[14] Clavigero, *op. cit.,* p. 106.

forests lie well to the north, where they were encountered by Link on his further journey. They did lie within the subsistence area of the mission as it was later established and therefore were probably within the range of the Indians of Guiricatá.

After a march northward of a number of days from San Fernando Link turned to the east in order to pass the mountains that rose more and more steeply between him and the projected goal, the mouth of the Colorado. "But the mountains were so difficult and cliff-like that they could not cross with their horses. They made a detour to find a less hard way and came to so great a desert, that, lacking water and fearing the loss of their worn-out horses, they abandoned for the time the enterprise."[15] They followed the western base of the San Pedro Martir Mountains probably to a locality behind Santo Domingo, then turned south until they effected a turning of the range, perhaps in the vicinity of Rosarito, thus coming into the waterless desert of San Felipe, which barred their further advance. The route was well known later to the Franciscans, who employed men out of Link's party. In the Franciscan expeditions Crespi and Cañizares stated that they followed Link's trail as far as the *cieneguilla*, presumably in the San Domingo basin, and perpetuated Link's naming of the arroyos de los Martires and de las Palmas, both still identified by these names and situated in the hill country northeast of Rosario.[16]

The Jesuit plans for the utilization of the site of San Fernando are given by Clavigero:

> There was proposed for the establishment of the projected mission no other site than that of Guiricatá, but since this was distant 60 leagues from Adac [San Borja], the mission would have been isolated, leaving between many heathen who could block communication between the two, or could at least make difficult and risky the transport of provisions from the one to the other. To reduce these inconveniences, the missionaries attempted never to plant a mission until the intervening savages had been christianized. It was necessary therefore to found a mission which would serve as a station on the way to the one they wished to establish at Guiricatá. This was effected in October, 1766, at Calagnujuet [Calamajue]. This place, although adjudged at first useless for such a foundation, which it was in fact because of the bad quality of the water, nevertheless was chosen because there appeared none better in all the great space between Adac and Guiricatá, and it was hoped that its alkaline water would serve at least for irrigating the land which was needed for cultivation. [The water, however, killed the crops which they planted and it became necessary to seek another site.] The Father Arnés, having suffered great discomfort at Calagnujuet and seeing that it was not possible to subsist in a place

[15] *Ibid.*, p. 107.

[16] Crespi, *in* Palóu, Noticias, vol. 2, pp. 48–55 (Bolton, ed.); Cañizares, MS diary in Bancroft Library, University of California.

so sterile and lacking in all things, undertook to find somewhere else a more tolerable location, and after many journeys found it in the arroyo Cabujacaamang [Santa Maria] in May, 1767. Its land is not so sterile as that which they abandoned, and although equally lacking in wild fruits, pasture, and wood, the little water in its arroyo is very good. There are also in it some palms of red wood, good to use, and the lack of fruits is compensated in some fashion by the abundance of good fishing in the Gulf. [Here they proceeded at once to build some] miserable cabins of wood covered with thatch, and to cultivate a small patch within the arroyo.[17]

The Jesuits probably would have elaborated this foundation of Santa Maria de los Angeles into as good a mission as Santa Gertrudis, but they occupied it less than a year. In 1768 they were expelled abruptly, their crops remaining unharvested, and of course their project for the greater mission at Guiricatá not yet begun. They had spent sixteen years, beginning with Consag's first reconnaissance, in getting familiar with the desert of San Borja, and in placing therein a series of missions. They had demonstrated their ability to extend their foundations through this bleakest of deserts, and they had found, through Link's explorations, the way through to a less forbidding country. A short distance ahead of them lay one of the fairest lands of the New World. In mastering the Desert of San Borja they solved the major physical problem in the occupation of the Californias.[18]

FRANCISCAN BASE AND DOMINICAN SUCCESSION

The preparations for the new mission had been completed by the Jesuits. The proper site had been chosen. Sufficient knowledge of the tributary territory had been secured. The necessary supporting mission had been launched. The local Indians were partially proselytized, beginning with contacts from San Borja and furthered by still closer connections through Santa María.

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[17] Clavigero, *op. cit.*, pp. 107–9.

[18] Riveroll's journal of the sixties of the past century, giving a list of the watering places along the camino of the padres, throws light on the character of the task carried out by the Jesuits. The majority of these watering places cannot be depended on in summer. The *legua* is approximately three miles.

San Ignacio to Santa Gertrudis	26	leguas, water at three places between
Santa Gertrudis to San Borja	32	leguas, water at three places
San Borja to Santa María	42	leguas, one waterless stretch of 13 leguas
Santa María to Cajon Aruba	4	leguas, perhaps the Jaraguay of today
Cajon Aruba to Agua Dulce	8	leguas, north of Cataviña
Agua Dulce to San Fernando	8	leguas.

(*In* anonymous publication, Lower California, San Francisco, after 1862).

When turbulent tribes in the mountains to the north projected an assault on Santa María and sought the support of the tribe of Guiricatá, "which was very numerous," they received instead assurances of the good esteem in which the Jesuits were held.[19] The Indians of the Buenos Aires district appear to have been near kinsmen of the desert people to the south. The San Borja Desert was an ethnic unit, if we can accept the word of the Dominican Sales that "the pueblos of San Francisco de Borja and of San Fernando are not distinguished from each other, but much from the rest in their speech."[20] At the time of writing the Santa María Indians had been transferred to San Fernando. Indeed, the founding of San Fernando was the conclusion of a major stage in the expansion of the missions, anticipated through physical and ethnic circumstances.

The Franciscans, on falling heir to the Jesuit missions, were in the position to act as executors of the Jesuit plans, among which the occupation of San Fernando was next in order. In the spring of 1769 Rivera y Moncada, in military command, the Franciscan Crespi, and Cañizares, as geographer, assembled at Velicatá, as the Franciscans transliterated the Indian term, to follow Link's trail northward and thus to reconnoiter a route by land to Alta California. This first division of the famous expedition that was to signalize the occupation of Upper California was directed as a matter of course to assemble at Velicatá, even then regarded as the frontier position, not as lying in unknown territory. Here the animals recuperated on the local pastures, after the hard crossing of the desert to the south. Rivera erected the first buildings, in one of which Junípero Serra, arriving with the second party in May of the same year, formally established the Mission, dedicated to San Fernando, Rey de Castilla. There was no pretense at discovery by either party. They had been directed to use this place as a base. Palóu states that the Governor "had charged the reverend father [Serra] that in case the mission of Santa María could not subsist on the site of its foundation he should move it to Velicatá, but that if they decided that it should remain, he was to found another one on the latter site."[21] In another account Palóu reports that the mission was founded because of its excellent location "and because it was very convenient for communication from San Diego to Old California, and because there were sixty leagues of

[19] Clavigero, *op. cit.*, p. 108.

[20] *Op. cit.*, p. 100.

[21] *Op. cit.*, vol. 2, p. 30.

sterile, waterless land to the next mission, that of San Borja," the account being written after the disestablishment of Santa María.[22]

The principals in the founding of Alta California, Serra, Portolá, Crespi, and Rivera, remained on the local scene only a short time, both parties hastening to begin operations in the territory to the north, urged on by the sudden development of international rivalry on the Pacific and the strategic importance of the northern coast. The newly established mission was left in charge of Father de la Campa and some soldiers, and was to serve as a supporting base for the northern operations. The Franciscans, it should be remembered, played a part in the plans of the Spanish government, whereas the Jesuits developed strictly their own program. Goods were shipped up the Gulf to the bay of San Luis Gonzaga and thence were carried by land to San Fernando by way of Santa María. Live stock was driven up from the south to San Fernando and thence conveyed to the new establishments in Upper California.[23]

In 1772 the division of the Californias was effected by which the peninsula was ceded to the Dominican order. The following year the Franciscans evacuated their missions in the peninsula, Palóu assembling the friars, their effects, and a store of supplies, at San Fernando, from which the general exodus took place. Thus, after a tenure of four years, the Franciscans quitted San Fernando, the only mission which they founded in Lower California. The Dominicans administered this and older missions to the south and built a series of new missions extending to the border, of which the first was the mission of El Rosario, founded in 1774, situated on the Pacific coast fourteen leagues from San Fernando.

THE MISSION SITE

The physical character of the mission valley is shown in detail in figure 3, the cultural landscape in figure 4, and the reconstructed plan of the mission in figure 5. The mission was placed at the most strategic point, namely, in the *portezuelo* or gap through which the Buenos Aires basin drains into the Arroyo San Fernando, at the point of issue of the springs from beneath the basin. To the east lies the arid but valuable range of the Buenos Aires plain. Here stock could

[22] Relación histórica de la vida del Padre J. Serra (1787), p. 69.

[23] Serra, *in* Arch. Sta. Barbara, vol. 1, MS.

graze and find sufficient water at the mission. In the valley, water could be applied to the terrace lands by diversion of the spring flow.

The hills flanking the valley are for the most part grano-diorite, moderately jointed. This rock, closer textured than ordinary granite, forms steep slopes and somewhat fretted ridge tops (pls. 32*b* and 33*b*). Metamorphic rocks farther to the west result in a still more rugged topography. Recent lavas occur farther down the valley and may have blocked it in part. The rugged country to the west deflected movement so that the mission site was in fact a strongly emphasized focus for all travel. One route led down the arroyo and crossed over to the mission of Rosario. Another skirted the Buenos Aires basin at the west and continued northward by way of San Juan de Dios. A third led east to the Gulf through the plains.

The mission fields were placed on silty terrace remnants in the valley, continuous with the lower levels of the Buenos Aires plain. They terminate downstream, as shown in figure 3, giving way to a rocky gorge. Other narrows in the valley floor are determined in part by basal patches of the conglomerate previously described. The similarity in surface and material of the valley floor and the adjacent Buenos Aires plain indicates a common origin. It appears that the valley floor was developed by the same ponding that filled the lowest levels in the Buenos Aires plain. The silt bears little resemblance to the alluvium of streams, especially not to that which characterizes drainage in arid lands. The present arroyo bed is a sandy wash, shifting with every flood. At the time of the mission settlement the arroyo is believed to have had a much smaller channel, perhaps not even a sandy or stony bed. The cultivated surface lies well above the level of flood inundation and has a fertile, but somewhat alkaline soil.

Short of Rosario, there is no locality comparable to this. There are other, in part permanent, water holes but not sufficient for the irrigation of fields. The mission enclosure commands a view of almost the entire former oasis and a long sweep of the Buenos Aires plain (pl. 33*b*). Forlorn though it is today, it is still a pleasant spot in a setting of dignity and charm.

PROGRESS AND DECLINE OF THE MISSION

The first account of the establishment in operation was given by Palóu on the occasion of his inspection in 1772. There had been, he said, 300 baptisms by September, 1771.[24] There were, however, only twelve families living permanently at the mission at that time, because only sufficient land to support this number had been placed under cultivation. The Indians of the outlying settlements took turns in coming to the mission for instruction and to labor in its development. He registered complaint concerning the alkaline character of the soil, its reduced yields of wheat, and the failure of fruit trees, cotton, and wine. The most important productive task was completed: a sufficient dam of earth and stone had been built across the valley below the spring. A start had been made in the breeding of live stock with 49 head of cattle, 40 sheep, 44 goats, and a dozen horse colts on hand. In three years the mission was on a basis of self-support and was contributing to sustain the Indians at the Santa María Mission.[25]

The site of the dam is shown in figure 4. Only poor vestiges of it remain today. From it irrigation ditches, stone lined and cemented, were led down the valley on both sides at the base of the hills. The more important ditch, on the side where the mission stands, was carried across a tributary arroyo by a stone aqueduct to feed a rectangular basin, 12 by 22 meters, adjacent to the lower fields. It is still in a fair state of preservation and is shown in plate 34*a*. It was well lined with cement and supplied with a single outlet. Near the lower limit of the cultivated area a small field was noted, lying some distance back in a tributary arroyo and unconnected with the general system of irrigation. It appears to have been watered by water caught in the arroyo after storms and probably was only occasionally farmed. Other fields of similar character lie farther down the arroyo. It is not known definitely that these were in all cases utilized by the mission population. In part they are probably of later date, possibly connected with mines now abandoned.

From the Dominicans, who operated the mission for half a century, we have word of the renewal of the church and of fragmentary administrative statistics. The latter are the only direct evidence of the growth and decline of the mission.

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[24] The baptismal records preserved in the Dominican monastery at Benicia, California, give a total of 390 baptisms to November 24, 1771.

[25] Palóu, vol. 1, pp. 215–16; vol. 2, p. 34 (Bolton, ed.).

The following figures of production[26] have been handed down:

	Sheep	Cattle	Goats	Horses Mules	Swine	Wheat	Maize (Fanegas)	Barley
1782	178	110	65	31		368	410	107
1784	310	152	136	25	40	700	260	
1785	287	113	147	12	22	950	140	
1786	279	107	181	24	19	940	120	
1787	130	88	122	29	32	400	130	
1788	109	38	87	20	20	29	70	
1793	202	113	128	150	33	767	100	
1794	100	77	34	51	3	515	104	
1800	?	?	?	?	?	660		
1830	?	?	?	?	?	20	28	40

In addition there was a small production of cotton. The report for 1787 mentions also a harvest of 650 fanegas of seeds, presumably an estimate of the amount of wild seeds gathered.

The first impression given by these figures is the modest scale on which the mission operated as a producing unit throughout its history. In its best days it was but a small rancho. Certainly as many cattle are to be found today on its lands as were kept in the days of the missionaries, though the other forms of live stock have disappeared entirely, excepting the horses needed for cattle-herding. Swine appear particularly ill-suited to the economy of such a desert rancho and their keeping must have been due to the predilection of the earlier missionaries. A similar number of sheep and goats could easily be grazed today in this locality if the people were interested in caring for them.

The amount of land that is contained in recognizable old mission fields is 127 acres, of which 25 are now under cultivation. If, in the days of the mission, the sandy wash that now forms a large part of the valley floor was smaller, the cultivated area was correspondingly larger. Even if there was no sandy arroyo whatsoever the amount of land lying between the ditches did not exceed two hundred acres. The crops that were grown needed only an economical distribution of water, the wheat and barley requiring light irrigation in fall or early winter, the maize heavier flooding in spring and early summer. In no case was a consumption of water indicated in excess of what the site could provide today. The amount of maize produced could be grown on twenty acres of land at a maximum, and on the average probably involved a plot of about ten acres. With a sufficient

[26] Summarized from MS Arch. Calif. State Papers, Missions, vol. 1; 1830 figures from Lassépas, U. U. Historia de la Colonización de la Baja California (1859)), p. 104.

dam, indeed, one might have expected to find a larger acreage under irrigation but for the fact that there was no more land available. The gorge below cuts out the valley terraces and the friars did not possess the means to irrigate the lands lying above the springs. There seems to be no warrant for Nelson's opinion that "from the size and length of the ditches water must formerly have been much more abundant than now."[27] The twenty-five acres now planted to alfalfa, wheat, and garden produce are handled most wastefully as to irrigation, by far the greater part of the water flowing down the arroyo unused in mid-season. It should be noted, moreover, that the present irrigation is directly from the *cienega,* the dam having long since ceased to function. Nor do the present inhabitants complain of lack of water. Rather, one hears still the old complaint of Palóu that the soil is too alkaline and that the land will not raise most fruits, such as figs in particular, and that it is too *salitre* for the cultivation of beans. Assuming even the higher figures of former productive surface, the yields are not impressive. In the best year on record wheat can have yielded scarcely more than fifteen to twenty bushels per acre. The alkalinity is of course original to the soil, and the excellent underdrainage makes it improbable that it has increased.

In view of these figures of production the population statistics are remarkably large. Fortunately the Dominican record of baptisms and burials[28] has been preserved, and furnishes an impressive story of the fortunes of the mission.

	Baptisms	Burials		Baptisms	Burials		Baptisms	Burials
1773	135	34,	1790	29	18	1806	1	27
1774	177	67	1791	29	15	1807	0	20
1775	656*	95	1792	18	26	1808	6	9
1776	114	259	1793	9	24	1809	6	19
1777	30	178	1794	15	29	1810	6	11
1778	36	54	1795	13	27	1811	2	14
1779	29	95	1796	7	15	1812	3	16
1780	35	365	1797	9	31	1813	4	8
1781	24	33	1798	7	19	1814	0	12
1782	37	54	1799	7	23	1815	12	7
1783	33	32	1800	7	72	1816	0	1
1784	47	84	1801	3	45	1817	0	8
1785	12	42	1802	7	26	1818	1	2
1786	22	29	1803	3	34	1819	0	0
1787	43	28	1804	7	16	1820	0	0
1788	31	38	1805	1	42	1821	0	4
1789	31	52				1822	0	0

* "Many more not enumerated."

[27] Mem. Nat. Acad. Sci., vol 16 (1922), p. 25.

[28] Collated from manuscript registers in Benicia monastery.

The originals of the mission reports in the California State Papers having been destroyed by fire, only very fragmentary figures on total population are recoverable. Those extant are:[29]

1772	296	1790	479	1793	525
1782	642	1791	506	1800	363
1787	567	1792	506		

The largest population of the mission appears to have been in 1775 or 1776. The Mission Santa María had been disestablished and most of its Indians had been transferred to San Fernando, thus accounting for the greater part of the discrepancy between the two tables cited. At this time the task of converting the *Indios gentiles* had been pretty well completed and they had been brought under mission organization in large numbers. An inspection of the population and parish records indicates that there must have been about fifteen hundred Indians at this time belonging to San Fernando.

From this early peak the recession is grimly rapid. A frightful death rate was concomitant upon their Christianization. More than a third of them died in 1776–77 and well over a third of the remainder in 1780, the latter apparently of smallpox.[30] The death rate continued high but there were no more devastating epidemics. Until the early nineties the introduction of Indians from elsewhere and births postponed the decrease in numbers. Thereafter, however, baptisms become negligible and deaths continue high, until the mission ceased to exist, apparently in the mid-twenties of the nineteenth century. The last inspection of the church register took place in 1823. Lassépas, on unknown authority, says that there were nineteen Indians at San Fernando in 1830. Smallpox, measles, syphilis, and consumption wiped out the Guiricatás and their kinsmen in little more than half a century. Some fled to the mountains and were lost sight of. As early as 1777 such a flight is recorded, an entire rancheria having decamped, probably fleeing from the first great epidemic.[31] Hawkes, in 1849, found "3 old Indians, the sole inhabitants," living in two huts and cultivating a field of corn and some melons.[32] In 1853 the mission was found in ruins, "except one small room which is roofed

[29] Condensed transcript in Bancroft Library.

[30] Sales, *op. cit.*, Letter 1, p. 94, places the date of this great epidemic a year later, but he is often inèxact in his use of dates.

[31] Rivera, *in* Transcr. Arch. Calif., Prov. St. Papers, vol. 1.

[32] Hawkes, J. D., *in* Browne, J. R., Sketch of Settlement of Lower California (1869), p. 139.

over and in which are kept some oil saints of little merit and some carved saints of similar class. About 1000 varas below the mission live 4 Indians, the youngest of which is over 70; they take care of the church ornaments and books of the mission."[33] According to local tradition the last survivor removed to Rosario.

The collapse of the mission was not influenced by contests between secular and monastic administrations, such as arose later. It had nothing to do with economic competition with white settlers, for there were none. Nor was it caused by any insufficiency in the site, by destructive exploitation of the land, or by natural catastrophe. These Indians simply were not fitted to withstand the diseases of the white man, which were sufficient to bring final and rapid destruction to an entire people. San Fernando is a perfect illustration of the fatal blessing of civilization to a long isolated group of primitives, even though there was little alteration of their habits of life, and the economic system was benevolent in purpose and almost if not entirely unaccompanied by violence.

ECONOMY AND LIMITS OF SUBSISTENCE AREA

The amount of cultivated land available is estimated as about 150 acres at a maximum. The figure cannot be in error by more than fifty acres, the uncertainty being in the amount of land destroyed by arroyo wash and in the number of occasionally farmed patches not included in the central irrigated section. From this land were obtained in a fair year a thousand to fifteen hundred bushels of grain. When the mission counted its greatest number of converts, the grain and meat produced apparently sufficed to feed the people one day in the week. Even after the great epidemics the crops cannot have been sufficient to feed half the population, under minimum standards of living. The mission occasionally was able to send out some foodstuffs to other places and was considered flourishing. Until after 1788 San Borja and San Fernando were the most populous by far of the Dominican missions.[34] Famine or serious want appear never to have been felt. How then explain the discrepancy between status of mission site and its population?

[33] Bol. Soc. Mex. Geog. y Estad., vol. 7, p. 348.

[34] Sales, *op. cit.*, statistical table.

The mission proper was the nucleus of an extensive area. At the mission the friars lived and maintained the religious observances. Here also most of the food was grown for the monks and for the more domestic *entourage* of Indians. To judge from baptismal and burial records, by far the greater part of the Indians, however, did not live at the mission but at outlying rancherias. In the parish records, at least seven such rancherias are designated: San Juan de Dios, so important a branch of the mission that some of the natives believe it to have been a separate mission, de las Llagas, Santo Domingo, San Luis, Santa Rosa, San Francisco, and San Miguel.[35] Most of these can still be identified. San Juan de Dios was an important watering place and has been abandoned only lately as a cattle ranch. San Miguel, thirty miles to the north, now known as San Antonio, is still occupied as a rancho, and contains the ruins of a kiln and an old stone corral. In the lower slopes of the "Martires" another stone corral is reported, reputed to mark the site of an ancient rancheria belonging to San Fernando.[36] At the Bay of San Luis Gonzaga on the Gulf, a rancheria was maintained for the Santa María Mission and probably continued after the latter mission was transferred to San Fernando, the landing being a port of sorts and of value for fishing. Other rancherias probably lay to the south of San Fernando, in an area now entirely deserted, but which is known to contain several dependable water holes. The actual subsistence area of the mission therefore extended from the lower slopes of the Sierra San Pedro Martir well into the desert south of the Buenos Aires plain and from the Pacific to the Gulf. There was available to the individual native at least a square mile of desert and steppe for his sustenance, and from this wild land and from the sea he drew the major part of his living.

A part of the Indians were definitely domiciled at the mission, though there were no extensive provisions made for housing natives (fig. 5). The poor quality of the grazing and the restricted occurrence of water resulted in division of live stock among a number of rancherias. Otherwise the régime of their life does not seem to have been much altered. In the main they continued to get their living as they had done before. They were still essentially primitive

[35] See Engelhardt, Z., Missions and Missionaries of California, Index Vol., p. 143.

[36] Sr. Santiago Espinoza, of Rosario, formerly the occupant of the ranch at San Juan de Dios, was able to identify five of the former rancherias.

gatherers. The seeds of the chamiso and mesquite, roasted hearts of the agave, and the fruits of the cactus, in particular cardon, cholla, and pitajaya, were supplemented by less toothsome but more constantly available products of animal origin. It is to be remembered that no parts of the local region were devoid of a vegetation that yielded edibles sufficient to provide sustenance at certain seasons, and supported and sheltered many small animals, particularly rodents.

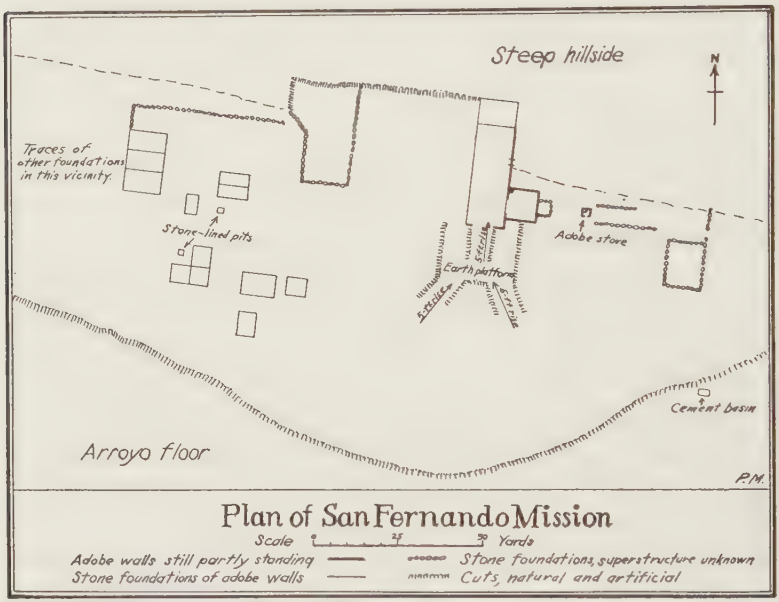

Fig. 5

Finally, the sea provided an especially rich food supply, and, though at a considerable distance, was much utilized by the Indians here as it was in almost all the missions of the peninsula. Serra recounted that near San Juan de Dios an Indian chief brought two *tercios* (about 300 pounds) of roasted agave and offered to send people to fish for the party. He noted also that the Indians at San Fernando were living on roasted agave and fish.[37] Cañizares declared the food of the local Indians to be cactus seeds, agave, and fish.[38] How another interior mission relied on the sea for its major food supply is stated thus by Link for San Borja: "If the two seas had not supported me and all the Indians we should have starved to death with the most

[37] Diary, *in* Out West, vol. 16, pp. 405–6.

[38] Transcript, Bancroft Library.

intensive cultivation possible."[39] It will be recalled that San Borja has similar but more severe natural conditions. The shores of the Pacific are particularly rich in clams, mussels, sea snails, and were a famous fishing ground for turtle, abalone, and crab until devastated by San Diegan and Japanese fishermen.

This was the nature of the range on which the Indians had their being. Their concentrations were casual and determined primarily by the presence of fresh water, so that even their rancherias probably were customary gathering places rather than definite habitations.[40]

AFTER THE MISSION

The mission and its oasis were in ruins by the middle of the last century. At present only a tiny strip of garden is watered on the side on which the mission stands, whereas a larger field remains under cultivation on the opposite side. It is worthy of note that the largest, longest, and most carefully constructed ditch lies on the right-hand bank, on the wrong side of the arroyo in terms of land now available for cultivation (fig. 4). The floor of the valley adjacent to it is now a particularly deep and broad wash of coarse sand and gravel. Here, apparently, the best watered field of the padres formerly lay. It is at this place that the only vestige of mission agriculture is to be seen in a few pomegranate trees. A visitor of 1853 stated that "the arroyo carried away in a flood all the lands of the garden (*huerta*), of which only a few pomegranates remain."[41] Further loss of land seems to have taken place still later, for we are told that in 1867 the mission overlooked "a marshy tract nearly half a mile long."[42] No marshy tract of such dimensions exists today. The latter author, a geologist and careful observer, appears to have found a reedy arroyo floor where today there is only detritus. The most reasonable interpretation is that, through the ruin of the dam, erosion was initiated which progressed both upstream and downstream from the dam site, sluicing out in particular the field immediately below the old dam.

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[39] *In* Murr, *op. cit.*, p. 400.

[40] In the vicinity of San Fernando the only vestiges of Indian culture noticed were petroglyphs in the arroyo below the mission, and smoke-blackened rock refuges on the way to San Juan de Dios. The coast is, however, very rich in shell accumulations.

[41] Bol. Soc. Mex. Georg. y Estad., vol. 7, p. 348.

[42] Gabb, *op. cit.*, p. 109.

During the California gold rush, miners, in particular Mexicans and Chilenos, accustomed to desert travel, made use of the land route through the peninsula to get to Upper California. Occasionally some of them located in the vicinity to prospect the surrounding hills.[43] In this manner a number of mineral prospects in the metamorphic belt were opened and also some small gold deposits in the desert to the south. Some of these mines are still worked intermittently. It was this infiltration that appears to have brought the first settlers from the mainland. The old camino of the padres is still an occasional highway for Mexicans, who work their way north by stages to the American land of promise. They find employment for a time at the copper mines of Santa Rosalia and at the onyx mines near San Fernando. With a burro, a water bottle, and a bag of beans and *carne seca* they find their way somehow over the desert trails, sharing in the meager fare of the few families who live scattered along them at infrequent intervals.

Gradually, this, the farthest frontier of Mexico, was occupied by vaqueros from the mainland, small cattlemen seeking free grazing land. A single family of this sort was in occupation of the mission in 1926, having lived there for a dozen years. Several more families, formerly living here, had drifted away in recent years, principally to the States, where fabulous sums are paid for labor and work is to be had always. These later residents have no connection with the mission history in blood or tradition. They are almost totally unaware of the former economy of the area, keeping only cattle and raising a little wheat and alfalfa. Though the country is better suited to sheep and goats than to cattle, they are not kept, and people share the cowman's aversion to these animals. Their agricultural skill is slight and their interest in agricultural possibilities even less.

To the east another culture succession has been brought by the mine of Mexican onyx at Onyx, or El Mármol. Here a village of about two hundred people, largely Yaqui, has developed under American initiative.[44] At Onyx water is almost lacking and of very poor quality.

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[43] Gabb, *loc. cit.*

[44] Mr. George Brown, the resident manager, has altered this section of the desert more than any other occupant since Father de la Campa. A well-ordered village has been built, an automobile road developed to the landing at Santa Catarina, and ranchos are established at Santa Catarina and San Augustín. Most of the food is imported from the United States, but the cultivation of land is succeeding at Santa Catarina, as Mr. Brown's hospitality amply demonstrated to his visitors, and a beginning has been made at San Augustín.

In the middle of the Buenos Aires plain, however, at San Augustín and El Águila, wells sunk to fifty or sixty feet have encountered good water. This development suggests the possibility of occupation of the Llanos by widely spaced stock farms, with small individual fields. Excepting at Onyx and its rancherias, the entire area of the Guiricatás is uninhabited today save for the single family at San Fernando and the one at San Antonio to the north.

The missionaries, who were able to establish a small oasis on a patriarchal system, disappeared from the scene with the extinction of their wards. The ruined mission is a relict of a culture period that remained without issue and which has been followed by a more complete return to wilderness conditions than this region has known. The collapse of the area is complete because there are no people available who could follow the economy of the primitive Indians and because there is no sufficient incentive other than mining to initiate a higher use of the land. It is not an area entirely without possibilities, however. Given the sufficiently modest demands of the small Mexican or Yaqui farmer, it is probable that enough water could be impounded or reached by shallow wells to support small ranches at intervals of several miles over the Llanos. A small village could be reestablished at San Fernando. Through grazing, very limited agriculture, and the protection or even planting of agave, a population comparable to that of the early mission days might possibly be reestablished. Such a condition is likely to develop, however, only when the more favored lands to the north cease to attract laborers and if the passageway of Buenos Aires becomes significant again as a highway between Upper California and the Sea of Cortés.

EXPLANATION OF PLATES

PLATE 31

a. Thorny chamiso in plain of Buenos Aires. Common ocotillo in center of view. Characteristic dwarf agave in right foreground. Desert pavement moderately developed.

b. Cholla cactus on slope behind mission. Cardon in background.

a

b

PLATE 32

a. Cirio "forest," upper Rosario Valley, near Aquajitos, looking out over coastal mesas.

b. Cardon and cirio in metamorphic belt between San Fernando and Rosario.

a

b

PLATE 33

a. Desert pavement or *pedregal* in the Buenos Aires plain.

b. At the portezuelo or head of the Arroyo San Fernando. Looking down the valley, mission in foreground, cultivated fields across the stream channel.

a

b

PLATE 34

a. Old reservoir in central part of Mission Valley.

b. Mission ruins of San Fernando de Velicatá.

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ALTERATION OF THE ARGENTINE PAMPA IN THE COLONIAL PERIOD

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ATTEMPTED SETTLEMENTS AND THEIR EFFECTS

Spain made her earliest attempts to gain a footing on the Argentine Plain in the first half of the sixteenth century, but extraordinarily well-equipped expeditions, such as that of P. de Mendoza,[1] failed utterly. The usual Spanish methods of colonization could not be imposed upon a population of nomadic hunters who were unwilling to accept the newcomers as their masters and to provide for their maintenance. Even when the Spaniards were able to resist the attacks of the Pampa Indians, as they did under Mendoza, they were driven out eventually by famine. An open fertile area, awaiting only the plow, did not appeal to the Spaniards of colonial times,[2] who had left their country in quest of tribute which they could levy by the sword. They preferred the conquest of central Chile, Perú, and even the forests of Paraguay where they found a sedentary Indian population having a highly developed agriculture and easy of subjugation.

Hence, in the first half of the sixteenth century, Spanish settlements appeared only as ephemeral cultural features on the Pampa. In 1526, Gaboto founded Fort Espíritu Santo on the banks of the Rio Carcarañá,[3] but the Indians conquered and burned it almost

[1] Gonzalo Oviedo y Valdés (–1557), Historia general y natural de las Indias (Madrid, 1851–1853).

[2] Diario de J. F. de Aguirre (1754–1811) *in* Anales de la Biblioteca, vol. 4, (Buenos Aires, 1905), p. 235: "á excepción de uno ú otro paraje, hacia la sierra en que no falta agua, leña y conveniencias para labrar la tierra, es inhabitable esta Pampa que a primera vista parece proporcionar tanta utilidad."

[3] Oviedo y Valdés, *op. cit.*, libr. xxiii, cap. 3: "alli hicieron los cripstianos asiento y casas de buhios de madera cubiertas de paja. E hicieron una fortaleza de tapias de tierra."

immediately; and Mendoza's Buenos Aires, founded in 1535 or 1536, and described by Schmidel,[4] was abandoned in 1541.

The influence of the Spaniards, however, was not restricted to the foundation of a few poor settlements destined early to disappear. Unintentionally they initiated at that early time an important alteration of the Pampa, which in the course of some decades effected a marked change in their own appreciation of the economic value of the area.

Hitherto the Argentine plains had been stocked only with herds of guanacos, deer, and rheas, and these constituted the main food supply of the Indians. Now, however, the runaway cattle and horses of the Spaniards began to multiply so quickly that within half a century large herds of wild cattle and horses roamed the Pampa.[5] The area thus acquired a novel economic importance. As early as 1581, Juan de Garay, the second founder of Buenos Aires, informed the Spanish king of the existence of wild cattle and horses in the Pampa, and asked him repeatedly to have this stock conceded as a grant to the inhabitants of Buenos Aires and Santa Fé.[6] At the same time this abundance of cattle and horses fundamentally modified the habits of the Indians. They soon became accustomed to ride horseback, thereby enlarging considerably the range of their hunting activities.

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[4] Ulrich Schmidel, Reise nach Süd Amerika 1534–1554 nach der Münchener Handschrift (Tübingen, 1889), pp. 27 and 30: "da haben wier ein stat gepaut, hat geheissen Bonas Ayers, das ist auf deuschs . . . gueter Windt . . . man pauet . . . eine erdene maur einen halben spies lanng hoch darumb; und darinnen ein starckh haus fur unseren oberstenn."

[5] E. v. Nordenskjöld, Deductions suggested by the geographical distribution of some pre-Colombian words used by the Indians of South America (Göteborg, 1922), refutes the assumption of Cardoso ("Antiguedad del caballo") that the horse existed in the Pampa in pre-Spanish times.

[6] Letter of Juan de Garay to the king of Spain from Buenos Aires, June, 1581, *in* Anales de la Biblioteca, vol. 10 (Buenos Aires, 1915), pp. 158–59: "avize a vuestra alteza como auia sabido que auia cierta cantidad de ganado caualluno cerca del asiento de buenos ayres procedido de unas yeguas que quedaron alli en tiempo de don pedro . . . cuando esto escriui no las haviamos visto y en effeto ay buen golpe dellas. . . . suplique a vuestra alteza hiziese merced a la ciudad de trenidad y a esta de santa fee de todo aquel ganado . . . torno a suplicar a vuestra alteza se nos conceda la merced de todo aquel ganado.'

SETTLEMENT FROM PERU AND CHILE

It was not until the second half of the sixteenth century that the period of permanent Spanish colonial settlement in the Pampa began, and continued for almost two and a half centuries. During this time and the succeeding decades of civil wars, a number of very definite agents were at work on the landscape and have left traces which are still visible.

The Spaniards advanced their settlements into the Argentine plains from three directions. The first expedition which settled definitely came from Perú. Its members subdued the sedentary Indians of the border mountains, who had been under the cultural influence of the Incas. Thence they advanced into the plains, Santiago del Estero (1553) being their first stronghold in the Argentine lowland. From there they founded in the following years Tucumán (1564) and Córdoba (1573). Communications with Alto Perú were maintained through bases which eventually expanded into towns, Salta (1582) and Jujuy (1583). During the whole colonial period, the province of Tucumán was in economic relation with the highland of Perú. The flourishing mining district on the adjacent high plateau to the north formed the almost exclusive market for its agricultural products and stock, especially mules, long before the Pampa had any economic importance.[7]

The reason that the first settlement of the extreme western part of the plains was made by Spaniards (Mendoza, 1561, and San Juan, 1561) coming from Chile is easily understood from a review of the original delimitation of the province of Chile by the king of Spain, whereby Chile was conceived as extending from the valley of Copiapó in the north to the Strait of Magellan in the south, and 150 *leguas* from the Pacific coast toward the interior.[8] The 150 *leguas* were an

[7] The route by which the Spanish settlements of Tucumán were founded seems not to have been at all an "impossible one," but the logical one for the Spaniards to have chosen at that time. To assume naïvely that the conquistadores proceeded as they did simply because they "rather specialized in doing impossible things" (M. Jefferson, Peopling the Argentine Pampa, Am. Geog. Soc. Research Ser., no. 16, New York, 1926, p. 8) certainly does not do justice to the economic development of South America in the sixteenth century.

[8] Título de Teniente General de la provincia de Cuyo a favor del Capitán P. del Castillo, 22 de Noviembre de 1560, *in* Revista de la Biblioteca Pública de Buenos Aires, vol 11 (1880), p. 105: "Por cuanto S.M. por sus reales provisiones me (Garcia H. de Mendoza) encargó la gobernación de estas provincias de Chile, de Norte Sur desde el valle de Copiapó hasta la otra parte del Estrecho de Magallanes, y Este Ueste ciento cincuenta leguas . . ."

arbitrary distance, since at that time nobody could do justice to the nature of the then unknown interior. Thus in early colonial times large parts of the Argentine plains came under the domination and influence of Spaniards from beyond the Andes.

A BASE ON THE LA PLATA

Settlement thus far was restricted to the interior monte area. But at length the settling of the eastern grassland began. It was not the Pampa itself that attracted the Spaniards. Asunción in the north had become a populous town in spite of its location far from the coast. Spaniards had easily subdued the numerous and peaceful Guaraní population of Paraguay with its well developed agriculture, and had found maintenance for themselves there. But further development of the area suffered from difficult communication with the mother-land. In nearly every case ships from Spain arrived at the La Plata in bad condition and with exhausted crews. A port was needed where they might recuperate from these hardships before starting on the long trip up the Paraná and Paraguay, a voyage almost as long as that across the ocean itself. With this purpose in mind, Spaniards from Asunción founded first Santa Fé (1573), and then Buenos Aires (1580),[9] hoping also that they would develop into starting places for overland traffic to Perú and Chile.[10, 11]

At the end of the sixteenth century the land around Buenos Aires and Santa Fé was the only part of the Pampa proper under direct cultural influence of the Spaniards, the Indians retaining possession of the rest of the grassland and thus isolating the Spanish colonies on the La Plata and Paraná from those in the western and north-western plains. From this contingency arose the notion of the "Frontera," the borderland between the land of the Spaniard and

[9] Bando de Martín Suárez de Toledo, Asunción, 1572, Archivo General Mitre, *in* Anales de la Biblioteca, vol. 10 (Buenos Aires, 1915), pp. 254–56; "donde tanto conbiene . . . porque se abra puerto y aya escala entrada y salida para el trato e comercio de nabios e jentes de los Reinos despaña como de la costa del Brazil."

[10] Letter of H. de Montalvo to the king of Spain, 1576, *ibid.*, p. 93: "pues se tiene entendido el gran comercio y trato que puede haver con el piru y a muy menos costa las mercaderias que no tienen mas que sola una embarcacion en españa asta llegar a esta tierra . . . "

[11] Montalvo, letter to the king of Spain, 1850, *ibid.*, p. 129: "ansi mismo ago saber a vuestra magestad en las demas cartas mias la utilidad tan grande que redundara a estas provinçias y a las del piru y a la de tucuman y a la de chile el poblarse y sustentarse aquel puerto de Santa Maria de buenos ayres."

that of the free Indians. The movement of this frontier back and forth became, and is still today in the north, one of the most significant features in the development of the cultural landscape of the Argentine plains.

During the whole colonial period the Frontera of Buenos Aires, as well as that of Santa Fé, remained almost stagnant. The colonies developed slowly. Buenos Aires did not become what Montalvo had expected of it: the main import harbor of Chile and Perú. A voyage such as that of Governor Alonso de Sotomayor from Buenos Aires to Chile (1583) was not likely to be soon repeated. It was only undertaken from necessity since Sotomayor's fleet arrived in such condition at Buenos Aires that it was unable to proceed through the Strait of Magellan to its destination.[12, 13] The people of Buenos Aires were thus obliged for a long time to subsist on what the colony itself offered.

The colony under such poor economic conditions did not attract many immigrants, and even those few who intended to come, Spaniards as well as foreigners, had first to overcome the obstacles which the Spanish government placed in the way of any kind of emigration.[14] The population of European stock increased therefore but very slowly. On the other hand, the mestizos became an important element in the colonies, where they were recognized as Spaniards.[15] The early Spaniards were apparently eager to procreate large numbers of half-breeds.[16, 17] Compared with these the number of imported Negro slaves was of no great importance.[18] This slowly increasing popula-

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12 Letters from Governor A. de Sotomayor to the king of Spain, January 17, 1583, and February 28, 1583, Archivo de Indias, *in* Anales de la Biblioteca, vol. 10 (Buenos Aires, 1915), pp. 181–87.

13 Document proving the services of Cristóbal Gonzales during the expedition of A. de Sotomayor from Buenos Aires to Chile (Potosí, November 2, 1592), *ibid.*, pp. 240–43.

14 Announcement of Governor Marin Negron threatening with capital punishment those who favor in any way the introduction of immigrants without license of the king of Spain, Buenos Aires, March 25, 1610, Revista del Archivo General de Buenos Aires, vol. 11 (1880), pp. 19–21.

15 F. de Azara, Descripción é historia del Parguay y del rio de la Plata (Madrid, 1847), vol. 1, p. 293: "Los conquistadores llevaron pocas ó ninguna muger al Paraguay, y uniendose con indias, resultaron multitud de mestizos a quién la corte declaró entonces por españoles."

16 M. del Barco Centenera, Argentina y conquista del Rio de la Plata (Lisboa, 1602), cant. 4, p. 30: "comiençan a hazer a puja hijos."

17 F. de Azara, *op. cit.*, vol. 1, p. 252: "como los españoles llevaban rarísimas mugeres y necesitaban muchas, echaron mano de las indias en clase de concubinas."

18 Concolorcorvo, El Lazarillo de ciegos caminantes desde Buenos Aires hasta Lima, 1773 (edition of the Junta de Historia y Numismática Americana; Buenos Aires, 1908), pp. 36–37, gives for Buenos Aires in 1770 the number of Negro and mulatto slaves as 4,163.

tion found plenty of room within the original frontier during the whole colonial period. The Rio Salado south of Buenos Aires and the Rio Arrecife in the northwest were not crossed until the nineteenth century.[19-21] (Fig. 1.)

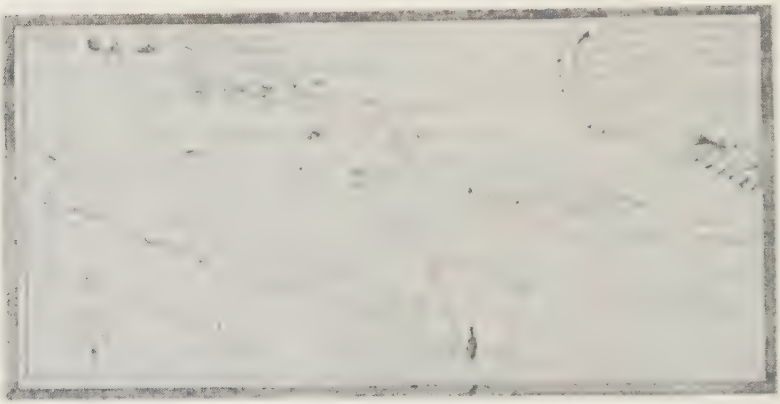

Fig. 1. The Frontier of Buenos Aires in 1779

ALTERATION OF THE PASTURE LANDS

The difference in culture between the free Indians and the Spanish colonists, separated for more than two centuries by the Rio Salado, eventually found visible expression in the landscape. The chief land utilization on both sides of the frontier was not essentially different. The Spaniards devoted themselves to stock-raising on most primitive lines. The Indians of the Pampa stole cattle and horses from them. The Spaniards reaped profit from their herds by exporting their hides;[22] the Indians drove their cattle over the Cordillera and sold

[19] New map of the southern parts of America, London, 1772, accompanying Thomas Falkner, A description of Patagonia (Hereford, 1774), contains the Indian boundary agreed upon in 1740.

[20] Plano de la Frontera de Buenos Aires que se reconoció por orden del Exmo. Sr. D. Juan José de Vertiz, Virrey y Capitán General de estas provincias. Buenos Aires, 1779, *in* Relación descriptiva de los Mapas, Planos, etc., del Virreinato de Buenos Aires existentes en el Archivo General de Indias, por P. Torres Lanzas. Publicaciones de la sección de historia. Facultad de filosofía y letres. N. VII, Buenos Aires, 1921. (Fig. 1.)

[21] Acarete du Biscay, Account of a voyage up the River de la Plata and thence overland to Perú (London, 1698), p. 20: "As far as the river Recife—30 leguas—I passed by several habitations and farms cultivated by Spaniards, but beyond the Recife to the River Saladillo I saw none." (The voyage was undertaken in 1658.)

[22] Martin Dobritzhoffer (1749–67, a Jesuit missionary in South America), An account of the Abipones, English translation from the Latin (London, 1822), vol. 11, pp. 218–22.

them to the Chilean farmers.[23, 24] But the land occupied by the inhabitants of Buenos Aires, and, to a lesser extent also that of Santa Fé, was so heavily stocked that the combined influence of man and animal produced an important alteration in the natural vegetation, especially, too, since the colonists were in permanent relation with Europe from which, quite incidentally, plants in increasing numbers were introduced.

The process by which the presence of cattle changes the aspect of the vegetation is well known to every stock-raising *criollo* as the alteration of pasturage, *a pata y diente*. By grazing, trampling, and spreading manure over the Pampa the stock itself changed the original vegetation. Man's active intervention consisted simply in burning the high hard grasses when they were dry. Azara[25] describes how the grazing of cattle, and especially of sheep, destroyed the higher elements of the Pampa vegetation (*pastos altos* and *pajonales*), and caused the alteration of the original Pampa into a lawn-like, low, dense sod. This occurred mainly in the moister part of the grassland which the Spaniards occupied. The observation does not hold true for the plains in their total expanse. In the more arid part of the plains, e.g., in the Córdoba area, one often sees "soft" grass growing among higher, hard grasses. The cattle by continual preference for the former keep it low or even destroy it, thus promoting in a short time the predominance of the higher, hard grasses. The different reactions of the natural vegetation of the Pampa to biotic agents in the moister east and in the more arid west, and also the fact that during the whole colonial period the moist east was more densely stocked, and, at the same time, invaded by many European plants, caused an especially conspicuous alteration of the old Spanish area. Darwin,[26] who crossed the old frontier at the Rio Salado near Guardia del Monte in 1833, was "very much struck with the marked change in the aspect of the country after crossing the Salado. From a coarse herbage," he writes, "we passed on to a carpet of fine green verdure. . . . The

[23] Espediente promovido por el señor síndico, sobre que se continue el reconocimiento del rio Negro, 1798, Revista de la Biblioteca Pública de Buenos Aires, vol. 11 (1880), p. 392: "el fin que tienen los indios de robar los ganados en esta juridiccion es, para conducirlos y venderlos en el reyno de Chile . . ."

[24] That the Spaniards did not find it objectionable at all to buy from the Indians the booty which had been taken from other Spaniards is stated by Dobritzhoffer, *op. cit.*, vol. 11, p. 17.

[25] F. de Azara, Descripción, etc., *op cit.*, vol. 1, p. 57–8.

[26] Charles Darwin, Journal of researches into the natural history and geology of the countries visited during the voyage of H.M.S. Beagle round the world (new ed., London, 1852).

plain looked like that around Buenos Aires, the turf being short, and bright green. I at first attributed this to some change in the nature of the soil, but the inhabitants assured me that . . . the whole was to be attributed to the manuring and grazing of the cattle. I am not botanist enough to say whether the change is owing to the introduction of new species, to the altered growth of the same, or to a difference in their proportional numbers."

This introduction of European plants into the area within the colonial frontier had indeed become an important factor in the development of this part of the Pampa. Azara[27] describes how great a number of imported plants followed the European into the Argentine plains. Not that the gaucho had cultivated them. He had adopted the habits of the Pampa Indian, taking no interest whatever in land cultivation. But unintentionally he prepared the channels through which the imported plants penetrated into the interior along the well used trails of his cattle and horses. Some of these introduced plants spread so quickly that they changed the whole aspect of the landscape. The wild artichoke (*Cynara cardunculus*) is the best instance of an imported weed which became rapidly naturalized. Some seeds are said to have been introduced into the La Plata area in 1769, lodged in the coat of a donkey brought from Spain. In the middle of the eighteenth century this weed was absolutely unknown in the area around Buenos Aires.[28] Early in the nineteenth century d'Orbigny and Darwin[29] noted that the southern limit of the artichoke was at the Rio Salado. North of this river on both sides of the La Plata the wild artichoke at that time covered hundreds of square miles of fertile ground. "In places the land as far as one could see was covered with a dense growth of cardoon thistles of a bluish-green colour."[30]

The invasion of the country by European plants was not restricted to a few species; it took place on such a large scale that at present only one-fourth of the plants growing wild in the Pampa are native. The *pastos tiernos* consist almost exclusively of imported plants such as Gramineae of the genera *Poa, Lolium, Avena, Hordeum, Cynodon,*

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[27] Azara, *op. cit.*, vol. 1, p. 57.

[28] J. J. von Tschudi, Reisen durch Südamerika (Leipzig, 1868), vol. 4, pp. 250–60.

[29] A. D. d'Orbigny (1802–57), Voyage dans les deux Amériques (new ed., Paris, 1854). After having crossed the Rio Salado, p. 233: "nous traversâmes les immenses chardonnières qui bordent tous les chemins . . . Ces chardonnières annoncent qu' on se rapproche de plus en plus de la civilisation."
Charles Darwin, *op. cit.*, p. 119.

[30] W. H. Hudson, Far away and long ago (New York, 1924), p. 69.

and soft herbs such as the *alfilerillo* (*Erodium cicutarium* L.), the *flor morada* (*Echium violaceum* L.), different clover species, such as *Trifolium repens, Medicago denticulata,* the hemlock (*Conium maculatum* L.), the fennel (*Foeniculum vulgare* Mill.), and many others.[31]

Not only the plant cover but also the animal life was largely altered. Large herds of cattle, horses, and sheep took the place of native guanaco, deer, and ostrich. Prejudicial animals such as rats[32, 33] and dogs[34-36] were introduced and multiplied so quickly that they became plagues, especially the dogs, which grew wild and were a great nuisance. They made such havoc among the calves that the whole industry of cattle-raising was endangered.

When the colonial period came to its close the vegetation and animal life of the Pampa, especially within the frontier of the area occupied by the Spaniards, had been almost completely changed through biotic agents.

The same period witnessed effects as great on human life in the Pampa. The Spaniards occupied the best part of the country along the Rio de la Plata and the Paraná, the Indians withdrawing into the

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[31] Berg, C., Enumeración de plantas europeas que se hallan como silvestres en la provincia de Buenos Aires y en Patagonia, Anales de la Sociedad Científica Argentina, vol. 3 (1877), pp. 181–206; Sobre plantas europeas que se encuentran en estado silvestre en las republicas Argentina y oriental, *ibid.*, vol. 4, pp. 30–33.

Seckt, H., Die Vegetationsverhältnisse der argentinischen Republik, Zeitschrift des deutschen wissenschaftlichen Vereins, Buenos Aires, 1918, pp. 1–48.

Devoto, J. A., Breves consideraciones sobre el problema forrajero en el pais (Rosario, 1926).

[32] Cabildo del 21 de Noviembre de 1611, *in* Acuerdos del extinguido Cabildo de Buenos Aires, 1907, vol. 11, pp. 186–87: "que . . . a causa del gran daño que haçen las hormigas y ratones en esta ciudad y sus terrenos se hechasen suertes para eligir Santo que fuese abogado para que esto çesase."

[33] A. Gillespie, Gleanings and remarks collected during many months of residence at Buenos Aires and within the upper country (Leeds, 1818), p. 120: "The great pests of Buenos Ayres are rats, which stumble upon passengers in the streets in numbers, and every morning many of their dead are strewed about, killed by men and dogs. Indeed the increase of that species seems to have kept pace with the cattle in those regions."

[34] Cabildo del 27 de Septiembre de 1621, Revista de Biblioteca Pública de Buenos Aires, vol. 11 (1880), p. 142: "en esta ciudad como en las chácaras de sus distritos, hay tanta máquina de perros que destruyen los ganados menores, y no dan lugar que se multipliquen; lo cual es muy gran daño de la república . . . lo cual visto . . . se pregone públicamente que ningún vecino . . . sea osado tener . . . mas de un perro."

[35] P. F. X. de Charlevoix, Histoire de Paraguay (Paris, 1756), vol. 1, p. 11: "Les chiens dont un tres grand nombre est aussi devenu sauvage . . . en (of the cattle) detruisent plus qu' on ne sauroit croire." P. 12: "si les boeufs disparoissent jamais de ce pais, ce sera surtout par la guerre que leur font les chiens."

[36] A. Gillespie, *op cit.*, p. 136: "large bodies of wild dogs, who live and breed in holes, were visible, in quest of water and food. Their hair is harder and thicker than the tame sort. They . . . tend much to diminish the general stock of cattle. I often noticed their preference to calves, which they attack in bodies of about twenty."

interior of the plains. Removed thus from the main river into a country without permanent streams, they could no longer live as formerly, in large villages along the Paraná and the La Plata where fishing provided them with plenty of food without the necessity of moving about. They therefore ceased to depend at all upon fishing and became exclusively hunters. The more uncertain returns from the chase, coupled with the easy and quick means of transportation which they acquired with the horse, made them more nomadic than they were originally. The type of Indian settlement became the *toldo,* a single tent pitched by one family, or the *toldería,* a group of skin tents occupied by several families who hunted together, but who easily separated when it seemed more convenient to hunt in smaller parties.[37]

HYBRIDIZATION ON THE FRONTIER

The Indians changed also racially through their proximity to the Europeans. They were accustomed to imitate the warfare of the Spaniard, killing the men and carrying away the women and children. The number of whites who in this way became incorporated into the different tribes of the Pampa Indians must have been very considerable[38-40] since the Indians were generally successful in their raids into Spanish territory.

The racial differentiation between the free Indian beyond the frontier and the most numerous element of the rural population within the frontier, the gaucho, was a gradual one. The typical gaucho was

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[37] The most intimate observation on the life of the hunting Indians of the plains is given by Dobritzhoffer, The life of the Abipones, *op. cit.*, and G. C. Musters, At home with the Patagonians (London, 1873).

[38] Order of the king of Spain given in Valladolid, November 20, 1539, to readmit all Christians who live among the Indians, Archivo de Indias, *in* Anales de la Biblioteca, vol. 8 (Buenos Aires, 1912), pp. 295–96: "Yo soy ynformado que . . . en esta provincia estan muchos Xrisptianos en poder de los yndios que no osan venirse donde estan los Xrisptianos . . . unos porque con las nescesidades y hambres que han pasado han comido carne umana, y otros que de hambre y con nescesydad se avsentaron del Real de los españoles . . . e se pasaron a los yndios por que les diesen de comer."

[39] Diario de Aguirre, 1783–98, *in* Anales de la Biblioteca, vol. 7 (Buenos Aires, 1911), p. 297, contains a letter of Presbítero F. A. González, March 23, 1789, referring to the Enimagas (Lenguas): "habian cautivado varios cristianos . . . que luego casaban haciendo aprecio de sus hijos; y asi hay entre ellos descendencia de cristianos, ya de mulatos, ya de españoles."

[40] Luis de la Cruz, Descripción de los terrenos poseidos por los Peguenches, 1806, Col. de Angelis, 1835, vol. 1, p. 36: "Tienan en sus tierras muchos españoles cautivos, unos y otros que se ocultan, y estos son nuestros peores enemigos." The author met on his trip from Chile to Melincué (Buenos Aires) quite a number of Spaniards living permanently among the Indians of the Pampa.

a half-breed of a Spanish father and an Indian mother, and his habits were similar to those of the free Indian.[41] This barbarous rural population was in sharp contrast with the urban population, the *criollos,* and the Spaniards of Buenos Aires and Santa Fé, representing European civilization.[42]

Yet in spite of the racial and cultural similarity of the free Indian and the rural population of Buenos Aires and Santa Fé, the Spanish colonial landscape developed in a particular way. Settlements of quite distinctive aspect and function arose and contrasted with the primitive *tolderías* of the free Indian.

Along the Rio Salado and the Arroyo de Arrecifes a number of so-called *guardias, fuertes,* or *fortines* were established, and in a similar way the more restricted area of Spanish colonization around Santa Fé was delimited.[43, 44] These forts formed a type of settlement peculiar to the area under Spanish influence. They marked the official frontier beyond which only a few Spaniards settled on the basis of good relations with the free Indians.[45] Nearly every author who reports on the La Plata region during colonial times describes one or several of these fuertes.[46] Their descriptions throw much light on the characteristic features of this type of settlement. Each fort was surrounded by a primitive fortification of palisades, or simply by a wall of thorny scrub surmounted by several small guns. The better ones had a ditch and a drawbridge. The garrison was always small, a few

[41] P. A. Garcia, Viaje a Salinas Grandes, 1810, *in* P. de Angelis, Colección de obras y documentos, etc. (Buenos Aires, 1835), vol. 3, p. xiii: "muchos de nuestros campestres, cuyos costumbres no distan muchos grados de las de los salvajes, se han familiarizado con ellos, y atraidos por el deseo de vivir a sus anchas; o bien temerosos del castigo de sus delitos, se domicilian gustosamente entre los indios. Estos transfugas, cuyo número es muy considerable . . ."

A. D. d'Orbigny (1802–57), *op. cit.,* p. 234: "Les habitants des estancias et en général les bergers de ces contrées, sont aussi peu civilisés que les Indiens; et leur manière de vivre a presque rendu sauvages les Espagnols qui l'ont adoptée."

[42] The classic picture of the contrast between the barbarous gaucho and the burgher of European civilization at the end of the colonial period, and during the following forty years, is given by Domingo F. Sarmiento, Facundo; civilización y barbarie en la República Argentina (Madrid, no date).

[43] Nota informe del cabildo de Santa Fé, sobre la defensa de aquella jurisdicción y género de guerra con los bárbaros enemigos, 2 de Setiembre de 1717, Revista del Archivo General de Buenos Aires, vol. 1, pp. 429–32.

[44] Nota del cabildo accompañando testimonio de sus acuerdos sobre defensa de la frontera, 17 de Noviembre de 1717, *ibid.,* pp. 438–40.

[45] Bando de Virrey Vertiz, ordenando al comandante de la frontera que recoja bajo la protección del cañon de los fuertes a las familias establecidas en parajes arriesgados en vista de los continuos ataques de los indios, 3 de Octubre de 1780, *in* Documentos para la historia del Virreynato del Rio de la Plata (Buenos Aires, 1912), vol. 1, pp. 304–5: "gran perjuicio resulta de hallarse varias familias fuera del Tiro del Cañon de los Fuertes."

[46] E.g., Dobritzhoffer, *op. cit.,* vol. 3, p. 87; and Concolorcorvo, *op. cit,* pp. 48–9.

Fig. 2. The Indian forts in the Argentine plains before the development of agricultu
(According to the map of A. Petermann *in* W. Parish, Buenos Aires and the Provinces of the R
de la Plata [London, 1852].)

soldiers,[47] usually married and having their families with them.[48, 49] The palisades enclosed a yard in which were huts for the garrison.

These forts were obviously not intended to form an uninterrupted line of defense against the Indians. The frontier was much too extensive and the population of the Spanish colony too small to attain such purpose. The forts were simply lookouts against the Indians, and their guns served not so much to defend as to warn the settlers of the neighborhood, to whom the fort offered shelter combined with the possibility of defense in the event of an Indian invasion or *malón*.

Hence the frontier marked by these forts (fig. 2) did not check sudden attacks by the Indians, who on frequent occasions penetrated even into the towns.[50] Dobritzhoffer recounts how the inhabitants of Santa Fé were once on the point of deserting their city[51] because they were not safe even on their way to church.

THE REDUCCION

A new form of settlement therefore appeared in the Pampa, the *reducción,* or Indian colony. These settlements were not of a single type. As a rule the Indians could only be induced by continual presents to settle on those places along the frontier which seemed convenient to the Spaniards and were acceptable to the Indians. They pitched their tents in the neighborhood of a fort from which they received not only their daily portion of meat, but also presents of manufactured articles. Being relieved of the necessity of procuring food, they thereupon renounced their normal habits of nomadic hunting. By this scheme the Spaniards reaped the double advantage of

[47] Diario de Aguirre, *op. cit.*, p. 183: "Fuera de la tropa veterana mantiene el Rey un cuerpo de 500 hombres con el nombre de Blandengues. Todos sus individuos son hijos de la tierra; excellentes ginetes de poca disciplina y que mas se acomodan a la lanza, bolas y lazo, que al fuego . . . . El destino principal de esta gente es la custodia de la frontera."

[48] Note of P. Groussac to the Diario de Aguirre, *op. cit.*, p. 250; "los mas son casados por lo que con otros vecinos que atrae siempre el sueldo, constituyen pueblos las guardias."

[49] P. A. de García, Diario de la expedición de 1822 a los campos del sud de Buenos Aires, *in* P. de Angelis, Colección, vol. 4, p. 11: "los soldados que ordinariamente era cada uno un padre de familia de que resulta . . . el aumento de población."

[50] Diario de Aguirre (1754–1811), *op. cit.*, p. 249: "Nuestra frontera . . . consiguió bajo el presente gobierno tan favorable establecimiento que se vive en Buenos Aires y toda la costa con mucha tranquilidad sin recelos de que vengan los pampas, lo que a mediados de este siglo estaba tan distante, que daban hasta en la capital."

[51] Dobritzhoffer, *op. cit.*, vol. 3, p. 14.

relief from Indian attack, and of protection, for these *indios mansos,* or tamed Indians, would even fight with the Spaniards against their savage brethren.

The most primitive type of such settlements of "allied Indians" was a simple *toldería,* located on the frontier and depending economically upon the Spaniards. Attemps to accustom the nomadic Indians of the plains to a permanent sedentary life, to teach them how to cultivate the soil, and to convert them to Christianity were seldom entirely successful.[52] The task was always left to the Catholic monks, of whom the Jesuits undoubtedly accomplished the most.

Dobritzhoffer[53] gives an account of the foundation of a typical Indian reduction, that of San Jerónimo on the frontier of Santa Fé:

> The Vice-governor with two fathers and a troop of soldiers went to the place designed for the colony. A small chapel, a little hut for the fathers and another for the chief cacique, were hastily constructed by the soldiers, of wood and covered with hay. The Abipones made use of their tents, till polished by some years' discipline they constructed handsomer edifices for sacred purposes for the fathers and themselves. The court yard of our house was surrounded with stakes, to guard against the invasions of savage enemies. . . . The first colony scarce consisted of 300 people . . . . subsequently more and more flocked thither . . . . the expectation of trifling presents, the beef which was every day gratuitously distributed, and security were magnets which drew numbers to the colony. . . . Sometimes the Abipones, not content with the ordinary portion, slew oxen without our knowledge. Detected and reprehended they would say: "That is no concern of yours, Father; the Spaniards must send more. They promised to do so when, at their request and for their convenience, we entered the colony. If they fail to perform their promises we shall return to our old way of putting them to death."

A few of these Indian reductions developed into permanent settlements attracting in the course of time some Europeans who lived on the trade with the Indians. Most of them served their purpose for a while but eventually fell into decay and were finally abandoned. Often a forlorn grove of peach trees in the Pampa alone remains as the last sign of the work of the Fathers in establishing these reductions.

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[52] Diario de Aguirre, *op. cit.,* cap. 10, De las reducciones de Indios, p. 385: "Las reducciones consisten en vivir los indios de ellas en paz con nosotros, pero perfectamente en su entera libertad. . . . Es menester darles hasta lo mas necesario . . . van continuamente auxilios de ganado a expensas del Rey, del vecindario y del remo de guerra, con menudencias de tabacco, etc."

[53] Dobritzhoffer,*op. cit.,* vol. 3, chap. 13, p. 391.

SETTLEMENTS BEHIND THE FRONTIER LINE

Behind the frontier the prevailing form of settlement in the colony was the isolated cattle ranch or *estancia*. The colonial Pampa, being a type of landscape in which stock-raising prevailed, naturally lacked villages. The estates were unfenced and extremely large, the distance from one dwelling to the next being as a rule several *leguas*. On the larger ranches there were a number of advanced posts (*puestos*), simple huts where a gaucho family lived and took care of the stock.

This one-sided attitude toward the use of the land became ingrained in the rural population, and can still be observed in the last survivors of the vanishing type of Pampa dweller. After a few generations of life in the Argentine plains the gaucho looked with utter contempt on any kind of agricultural work, although it had been the main occupation of his Spanish ancestor. As a consequence, cultivation of the soil was restricted to a minimum, farms or *chacras* being few in number and hardly sufficient to provide the colonial population with agricultural products. In the mind of the colonial Argentine, the Pampa had no other use than to provide fodder for cattle, horses, and sheep.

This particular attitude was reflected even in the aspect of the rural settlements. The early settlers, immigrants from Spain, did indeed plant a few trees around their dwellings and grew vegetables in fenced gardens behind their houses. But even this custom had quite disappeared by the first half of the past century.[54] Since the climate was not severe, little attention was paid to the dwelling itself. A poor mud hut—rancho—was sufficient as *puesto* for the gaucho, and a simple adobe building was the ordinary house of the *estanciero*. No shelter for the cattle was necessary; only a fenced corral for horses near the house.

In addition to estancia and chacra, another type of rural settlement with different functions had its origin in the Pampa—the *pulpería*,[55] which was at the same time, store, saloon, and banking institution for the scattered population of the plains. The general custom of traveling on horseback made it accessible even to the more distant dwellers. The gauchos spent their free time in the *pulperías*, which became the social centers of the Pampa. Business was also carried on in them and news obtained of escaped cattle and horses.

[54] W. H. Hudson, Far away and long ago, chap. 5.
[55] D. F. Sarmiento, *op. cit.*, chap. 3.

DISPERSAL DURING THE PERIOD OF PEACE

The general peace with the Pampa Indians which lasted from 1790 to 1815 changed the whole scheme of settlements in the Argentine prairies. The frontier lost its essential function as a line of defense against hostile Indians. Rural settlements—chacras and estancias—grew freely beyond the Rio Salado. The forts themselves fell into decay and around their ruins new centers grew, little villages with church and pulpería.[56]

The manner of landholding beyond the official frontier was rather unique. Garay, the founder of Buenos Aires, had divided the area around the town into a few extensive grants and had bestowed them upon his followers. According to a census of 1774,[57] only 186 persons in the whole rural part of the colony owned land, due to this limited distribution. Settlers entering on these estates during the peace with the Indians were simply usurpers, as free land existed only beyond the frontier. The situation of these squatters was not enviable. If the Indians spared their farms, there was always the danger of someone in the capital procuring a lawful title to the land, upon which they would be summarily ejected.[58]

The renewal of warfare by the Indians after this era of peace found the settlements of the Spanish colony without an organized system of defense. Their new invasions had therefore a great effect on the cultural landscape. Colonel García,[59] who crossed this region in 1822, remarks on the aspect of the Pampa north and south of the Rio Salado. All dwellings beyond the old frontier were burned down and only small peach orchards remained to indicate the sites of former Spanish settlements.

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[56] P. A. Garcia, Diario de la expedición de 1822, etc., *op. cit.*, pp. 6–11.

P. A. Garcia, Viaje a Salinas Grandes—1810, *in* P. de Angelis, Colección, etc., *op. cit.*, vol. 3, p. xiii: "Las guardias de fronteras que tenemos, son casi totalmente inútiles; porque están las más en el centro de las poblaciones, por su estado ruinoso, por falta de armas y soldados . . . de modo que las haciendas y poblaciones avanzadas al enemigo de 20–60 leguas al sud, estan francas y sin reparo alguno. . . . Se han visto precisadas las familias, contra lo estipulado en las paces celebradas con los Pampas, a pasar los limites del Rio Salado."

[57] Quoted *in* J. A. Garcia, La ciudad Indiana (ed. 3, Buenos Aires, 1900), p. 257.

[58] *Ibid.*, pp.19–21.

[59] P. F. Garcia, Diario, etc., *op. cit.*, pp. 48 ff.

URBAN CENTERS

The two urban settlements of the colonial Pampa—Santa Fé and Buenos Aires[60]—developed extremely slowly and for a long time lagged far behind Asunción. In 1657, according to M. Acarete du Biscay,[61] each of them was an unfortified place of about four hundred houses and a small fort. The one-story houses were built of adobe thatched with canes and straw. Santa Fé, especially, located not far from the frontier, suffered from the invasions of the Indians,[62] while the inhabitants of Buenos Aires were, for a long time, reduced to extreme poverty. A voluminous correspondence directed to the king of Spain shows that the Spaniards of Buenos Aires and their wives were obliged to do manual labor, a situation which of course appeared quite intolerable to the descendants of the conquistadores.[63, 64] As late as 1778 the census showed a population of 25,000 for the town itself. Primitive stock-raising could support only a very sparse population in the country; hence, compared with the rural population—13,000 in 1778—the size of Buenos Aires at the end of the colonial period would seem to be considerable.

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[60] A good study on the urban geography of Buenos Aires has been published by F. Kühn, Buenos Aires: Eine siedlungsgeographische Studie, Mitteilungen des Deutsch-Südamerikanischen Instituts, 1914, Heft 4, pp. 267–87.

[61] Acarete du Biscay, *op. cit.*, pp. 16–18.

[62] Nota del Cabildo de Santa Fé sobre establecer tres fuertes en su frontera guarnecidos con los cien soldados del destacamiento, 8 de Octubre de 1717, Revista del Archivo General de Buenos Aires, vol. 1, pp. 437–38.

[63] Carta del Cabildo al Rey, Buenos Aires, 8 de Abril de 1598, *in* Correspondencia de la ciudad de Buenos Aires con los Reyes de España, 1915, vol. 1, p. 38: "y ansi quedamos tan pobres y necesitados que no se puede encareser mas de que sertificamos que aramos y cavamos con nuestras manos . . ."

[64] Petición de Ihoan dias de ojeda, procurador general de Buenos Aires, 20 de Febrero de 1606, *in* Correspondencia de la ciudad de Buenos Aires con los Reyes de España, 1915, vol. 1, p. 169: "la mayor parte de los dichos vecinos y algunos de los dichos conquistadores . . . y sus mugeres y hijos van personalmente a buscar y a trabajarlo . . ."

THE CHANGE TO THE CURRENT SYSTEM OF LAND OCCUPATION

Throughout the colonial period the Spanish influenced only a restricted part of the Pampa: the land between the Rio de la Plata and the Rio Salado, and a less extensive area around Santa Fé (figs. 1, 2). Economic activities within the frontiers were almost entirely restricted to primitive stock-raising. As late as 1880, Buenos Aires imported grain. Physical labor, such as agriculture requires, was looked upon with contempt.[65]

The war of independence did not bring with it a change in attitude toward the land. The government passed from the Spaniards to the half-barbarian gauchos. European immigration became even less numerous than it had been during the colonial period. Only in the middle of the past century, with the fall of the tyrant Rosas, did the Argentines of European stock come into power.

This event initiated a fundamental change of attitude toward the land. With the development of modern industry, Europe was offering an increased market for agricultural products. The Argentine landowners began to realize that primitive methods of stock-raising could not supply this new market with the high grade beef that was required. Since the rural gaucho population was neither numerous enough nor inclined to do the necessary land cultivation, immigration became urgent. From 1857 to 1914, over four and a half millions[66] of immigrants came into the country, Italians leading with two and a half millions, followed by the Spanish with one and a half millions.

This population brought with it an attitude toward the land quite different from that of the native Indian, the colonial Spaniard, or the gaucho. Its interest was centered upon the agricultural utilization of the fertile Pampa soil. The cultural development of the landscape took therewith a new line of development. As might be expected, with the rapidly increasing population the area within the colonial frontiers became too restricted. Hence the Indian border, which had been stable throughout almost three centuries, was steadily advanced even

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[65] Azara, *op. cit.*, vol. 1, p. 304: "los españoles campesinos se dividen en agricultores y pastores ó estancieros. Estos dicen á aquellos que son mentecatos, pués si se hiciesen pastores, vivirían sin trabajar y sin necesidad de comer pasto como los caballos, porque asi llaman á la ensalada, legumbres y hortalizas. En efecto solo cultivan la tierra los que no pueden proporcionarse tierras y ganados para ser estancieros ó no encuentran otro modo de vivir."

[66] These and the following figures according to the third Argentine National census, 1914.

beyond the limits of the Pampa proper (see map). Finally even the defensive system was abandoned, the expedition of General Roca (1879) having driven the last wild Indian beyond the Rio Negro.[67]

Agriculture carried on by European immigrants did not, however, replace stock-raising. By a kind of idiosyncrasy, the *criollo* landed proprietor remained essentially a stock-raiser. Yet he took advantage of the immigrants, renting certain parts of his estate to them for short terms, with the obligation of returning the fields planted to alfalfa. He thus obtained the improved pasturage which his higher grade stock required.

Under this system, the land itself remained largely in the hands of old native families, and only a small portion passed to a permanently settled peasantry. There was little opportunity for independent founding of individual farmsteads which was so characteristic in the peopling of the North American agricultural areas. Only where private enterprise organized colonization by subdivision of large estates such as had been done early in the Santa Fé area,[68] did any considerable number of European peasants obtain a definite ownership of property.

The native landowner thus was benefited as much as the European immigrant by the new economic era which was initiated in the middle of the past century. But in the readjustment nothing was left for the gaucho, apt only for cattle-raising in its most primitive form. He had to yield before the flow of European immigration.

The economic defeat of the old native gaucho by the newcomers of European stock marks a rather pathetic episode in the formation of the Argentine nation. Today he is the hero of the Pampa traditions in the legendary incarnation of "Santos Vega."[69] This legend records for the Argentine people all that was noble in the gaucho of old, while at the same time it recognizes, in the figure of Juan Sin Ropa, the superiority of the poor but industrious immigrant who redeemed personal labor from dishonor, and who not only peopled the Pampa, but brought about with his plow the last and most fundamental cultural transformation of the landscape.[70]

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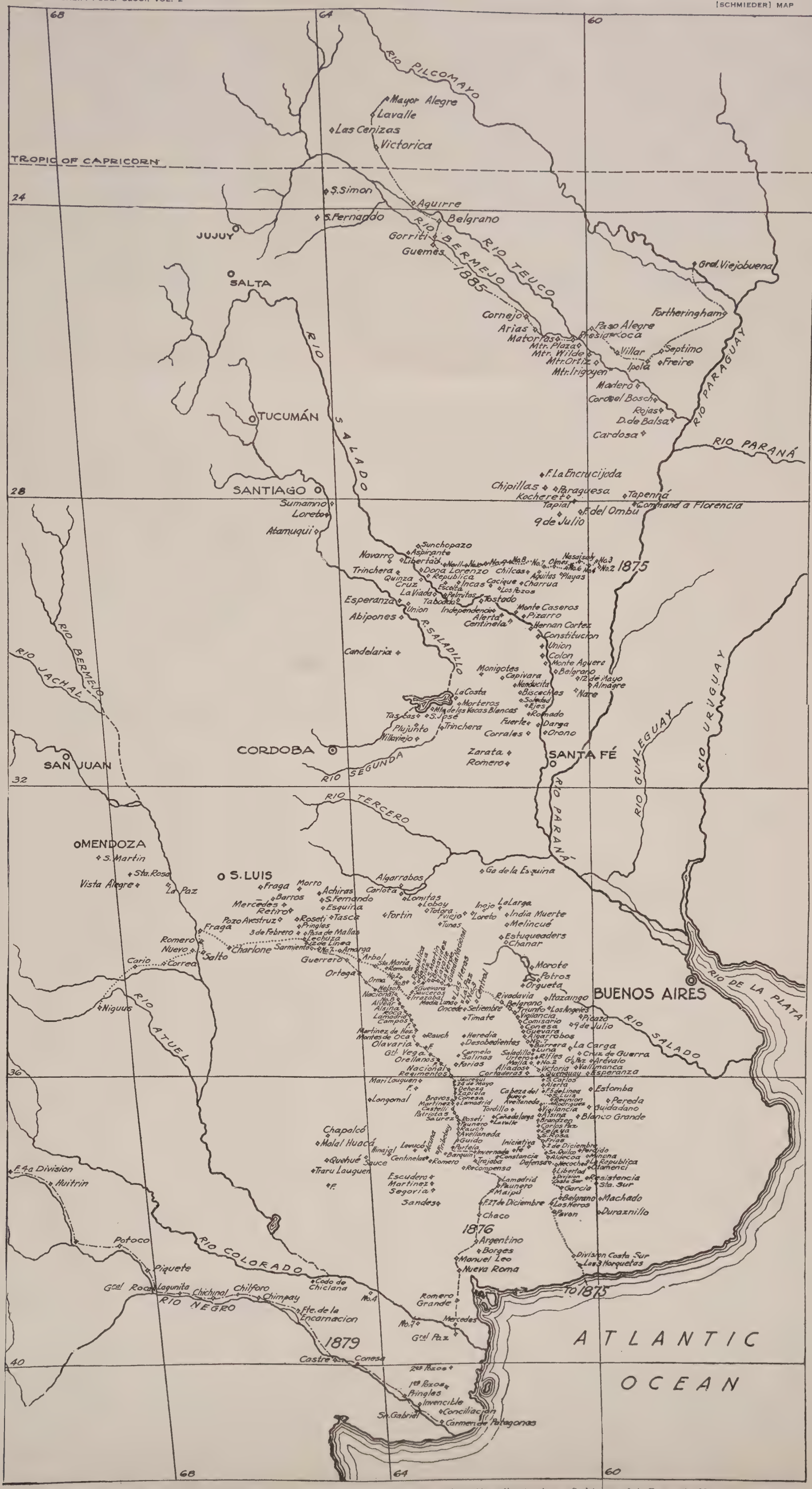
[67] A. Doering and P. G. Lorentz, La expedición al Rio Negro, 1879, Boletín de la Academia Nacional de Ciencias, Córdoba, Arg., vol. 21 (1916), pp. 301–86.

[68] M. Jefferson, Peopling the Argentine Pampa, *op. cit.*

[69] R. Lehmann–Nitsche, Santos Vega, Boletín Academia Nacional de Ciencias, Córdoba, Arg., vol. 22 (1917), pp. 1–436.

[70] Rafael Obligado, Santos Vega, Tradiciones Argentinas (Buenos Aires, 1885):

"Era, en medio del reposo
De la Pampa ayer dormida,
La visión ennoblecida
Del trabajo, antes no honrado;
La promesa del arado
Que abre cauces a la vida."



The Indian forts established in the Argentine plains since the beginning of agricultural expansion. (According to: A. von Seelstrang and A. Tourmente, Mapa de la República Argentina. 1:4000000 [Buenos Aires, 1875]; Die argentinischen Territorien der Pampa etc. nach den Aufnahmen der Expeditions-corps des General Roca. 1:4000000 [Petermanns Mitteilungen, vol. 27, pl. 5 (Gotha, 1881)]; F. Host and J. Rittersbacher, Karte der Militärgrenze am Rio Neuquen. 1:1000000 [Zeitschrift der Gesellschaft für Erdkunde, vol. 17, pl. 2 (Berlin, 1882)]; J. Rohde and S. Quiroz, Karte des argentinischen Chaco. 1:2500000 [*ibid.*, vol. 21, pl. 1 (Berlin, 1886)]; Luis Brackebusch, Mapa de la República Argentina. 1:1000000 (Gotha, 1891).)

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THE LAND FORMS OF SURPRISE VALLEY, NORTHWESTERN GREAT BASIN

BY

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INTRODUCTION

Location.—Surprise Valley is located in the northeastern corner of California. From its northern end, 7 miles south of the Oregon line and 6 miles west of Nevada, the valley runs slightly east of south for 54 miles, its southern end lying in Nevada, 2 miles across the state line. For a few miles at either end of the valley there is a gradual narrowing; elsewhere the width remains remarkably uniform at about 8 miles, few departures of more than 2 miles from that figure occurring for almost 50 miles (fig. 1). Surprise Valley is shown on the Alturas (California), and Long Valley (Nevada) quadrangles of the United States Geological Survey.

West of Surprise Valley is the Warner Range, of California, east of its southern half is the Hays Cañon Range, of Nevada, and east of its northern half is an irregularly block-faulted area to which no special name has been applied, excepting that locally it is sometimes spoken of as the "New Year Lake country" (fig. 2).

At present the valley needs no outlet for surplus waters. Thus, in respect to drainage, it lies within the Great Basin. In respect to earth structure it lies almost at the margin of, yet within, the Basin Range province, as both the Warner and Hays Cañon ranges are typical examples of structurally simple Basin ranges.

The summit elevations of the Warner Range vary from about 7,500 to almost 10,000 feet above sea level. Those of the Hays Cañon Range are only slightly less lofty. In the New Year Lake country

summit elevations range between 6,500 and 7,400 feet. The center of the valley has an elevation of about 4,600 feet, so that the local relief varies from slightly less than two to somewhat more than five thousand feet. Nearly all the slopes bordering the valley are striking and steep, particularly those of its southern half. In less than four miles, horizontally, one may descend from Eagle Peak, in the Warner Range, more than five thousand feet, to the valley floor. Across the valley the slopes of the Hays Cañon Range are of much the same order of steepness.

Fig. 1. View south from near Eagleville showing shore lines of Lake Surprise, a portion of the delta of Emerson Creek, part of the southern end of the Warner Range front, and parts of the Western Valley Slopes and Grass-lands.

Climatically Surprise Valley is a borderland between Cold Steppe (*BSk*), and a winter rainfall type of Microthermal (*Ds*) climate.[1] Toward the west is a humid climate characterized by warm summers and cold winters, during which the ground remains frozen for a month, or more, each year. Temperature conditions are still more rigorous toward the east but of greater climatic significance is the fact of lessened precipitation values in that direction.

The western slope of the Warner Range is sufficiently well watered so that it furnishes a small surplus which enters the Pit-Sacramento river system and ultimately reaches the Pacific Ocean. East of the Warner Range summits there is basin drainage only. The climate is

[1] Russell, R. J., Climates of California, Univ. Calif. Publ. Geog., vol. 2 (1926), pp. 73–84, 1 map.

sufficiently arid so that practically all of the lakes are not only without outlets but most of them are playas, remaining dry throughout the greater part of each year.

In the humid climate, toward the west, the summer months receive little or no rainfall, whereas comparatively heavy precipitation occurs during the winter. Toward the east there is less rhythm of precipitation, as thunder showers during the warm months materially lessen the seasonal contrast. In the Warner Range, and to the west, most of the erosion by running water takes place in the early spring, when the snow melts, and only occasionally during summer showers. East of the Warner Range the winter snow blanket is light and practically all running-water erosion accompanies thunder showers, which frequently are of cloudburst intensity.

Structure.—The Warner and Hays Cañon Range fronts exhibit the same stratigraphic sequence, a thick andesitic series, mostly pyroclastic, overlain everywhere concordantly by a thin layer of basalt, which in turn here and there is capped by concordant flows of rhyolite and, in places, by obsidian. Step-faulting is characteristic of both fronts so that a given stratigraphic sequence is often repeated several times between the range crest and base. At many places the capping basalt is found on, or close to the level of, the floor of Surprise Valley. Thus the structure of the valley is that of a graben, a fact which accounts for its shape, particularly as regards uniformity in width. The faulting responsible for the differences in elevation between range crests and valley bottom is still in progress, as is indicated by numerous recent fault scarps near the range bases and by numerous hot and cold springs placed in distinct relationship to these faults.

Purpose and limitations of this paper.—The primary purpose is to describe and outline the distribution of several different types of land surface in Surprise Valley. A secondary purpose is the description of a Quaternary lake which occupied the valley. To a very considerable extent these purposes are related, as several elements in the present land surface would not exist if it were not for the old lake. It is not pretended that any great degree of finality can be attached to the conclusions here presented. The observations upon which they are based were made incidentally in connection with field work in the Warner Range, in which the writer has been engaged during several summers.

LAKE SURPRISE

Israel C. Russell[2] was the first to call attention to the existence of a Quaternary lake in Surprise Valley and described it as being "the deepest, and perhaps most interesting" lake studied during his reconnaissance in the northwestern Great Basin during 1881 and 1882. He noted "the highest beach-line" as "a conspicuous feature throughout the valley . . . . drawn as a contour-line on its sides at an elevation of 550 feet above the surface of the lake-beds that floor the basin." Though he did not devote any great amount of time to the study of this area he reached several interesting and apparently correct conclusions in regard to it. To quote further:

> The former lake not only filled Surprise Valley, but overflowed across the narrow divide at its southern end, and covered Duck Flats as well. The lake thus formed was 70 miles long, with an average breadth of between 6 and 7 miles. There is evidence that it had two high-water stages, separated by a time of aridity when the valley was nearly, if not completely, desiccated.

Russell recognized the Surprise Valley Quaternary lake as being distinct and separate from Lahontan but did not apply any particular name to it. As far as the writer is aware no name has since been given, hence the name Lake Surprise is suggested and will be used in this paper in referring to the Quaternary lake.

The old levels of Lake Surprise are marked most clearly by corrasion features, in particular by truncated spurs, wave-cut terraces, and sea cliffs. The high-stage shore line is particularly well marked and surrounds most of the valley as yet in unerased condition. It extends to the left, in figure 1, from the tops of the tall, dark trees, at the right of the picture. Below this line are several others, always far less distinct and usually interrupted by gaps which render it difficult, and in some cases impossible, to follow them for any great distance.

The most conspicuous depositional features, in connection with the lake, are old high-gradient deltas at the mouths of the larger cañons. These are essentially alluvial fans which were built partly below water and for the most part when the lake was at its high-water stage. The now dissected delta of Emerson Creek, in the southwestern part of the valley, is shown in figure 1. Other depositional features, such as bars, spits, hooks, or extensive beaches are rare, chiefly on account of the steep off-shore gradients of the submerged range fronts which bordered the lake on most sides.

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[2] Russell, I. C., U. S. Geol. Surv., Fourth Ann. Rept., 1884, p. 459.

It is difficult to form any judgment as to the exact depth of sediments which collected in the bed of Lake Surprise. Several fairly deep wells have been drilled in the valley, the deepest, at Cedarville, reaching a supposed depth of 835 feet. In this entire distance the driller reports "lake sediment" containing notable amounts of organic material, described as reeds and grasses. This suggests meadow, marsh, and shallow water sedimentation, possibly not greatly different from that taking place today. It seems probable that the sediment which collected in the lake itself forms a relatively thin veneer over this great bulk of valley fill. The boundary between the two is not

Fig. 2. Salt Works east of Cedarville, located in the Salt Flats near the Hummocks area and not far west of the Sand Dunes Surface, showing a portion of the Hays Cañon Range front.

known to be distinct, or even discernible. It seems reasonable to suppose that the beginnings of the lake took place slowly and without any sudden or marked changes in climate, vegetation, or sedimentation. The upper twenty or thirty feet of sediment, however, seem to have been deposited in the lake, at least for the most part. In the center of the valley this material consists almost entirely of finely bedded white clay and shale which, in marginal situations, is interbedded with sandy and gritty layers.

A few feet below the present surface of the valley center there is a zone of relatively pure salt layers. These are being exploited about three miles east of Cedarville, where the small salt works, shown in figure 2, have been erected. There the ground water is a strong

brine and is readily lifted ten feet, or less, by means of both wind and gasoline power. Concentration and final evaporation yield salt pure enough for cattle and, now and then, for cooking and table use. Probably Russell's evidence of two high-water stages, separated by a time of aridity, was largely based upon this salt zone.

The high-stage shore line of Lake Surprise has an elevation of approximately 5,100 feet.[3] No departures from horizontality were noted anywhere along this line. In this respect it resembles the high-stage shore of Lake Lahontan, recently described by Jones.[4]

At the 5,100 foot elevation Lake Surprise reached an outlet and overflowed toward the south into Dutch Flat, an inclosed basin and one which in all probability already had in it a growing lake. The outlet area is a southern extension of the graben structure of Surprise Valley. For two or three miles the overflowing waters traversed a comparatively flat floor of basalt a mile or more in width. Under these conditions it seems probable that the initial cutting of an outlet gorge took place quite slowly and that Lake Surprise reached a resting stage during which high-level shore-line features started to develop.

Conspicuous shore lines around the Duck Flat basin suggest that the Quaternary lake there reached a comparatively long resting stage. Here again only the high-stage shore line is sufficiently well defined so as to be traced readily for most of the distance around the basin. The elevation of this line was not determined in connection with the present work but very probably it is the same as that of Lake Surprise in Surprise Valley itself. In the outlet region between the two basins the shore line is not at all plain, probably because no waves of any considerable size could originate or last long there. Standing in this region, however, one may see clearly the high-stage shore lines in both basins and it seems evident that one is the continuation of the other. That this line should so nearly approximate the elevation of the original outlet seems to be a matter of coincidence.

After the filling of Duck Flat basin Lake Surprise reached its greatest extent, the condition shown in figure 3.

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[3] This was determined from two profiles surveyed across the Warner Range by the writer. Forest Service elevations were used as standard in this work. The character of the survey and the accuracy of controls were such that the 5,100-foot elevation probably is accurate to within 10 or 15 feet. A small field transit was used in most of the surveying work referred to in this paper but parts of it were carried out with a more accurate mining transit.

[4] Jones, J. C., Carnegie Inst. of Wash., Publ. 352, 1925, p. 50.

Fig. 3. The area covered by Lake Surprise when at its greatest extent. At the south is shown the approximate position of the nearest edge of Lake Lahontan and in dots the present shore line of Pyramid Lake. The dashed lines are present streams flowing into the Blackrock Desert part of the Lahontan Basin. Those immediately south of the southern, Duck Flat, part of Lake Surprise are regarded as possible outlets into the Lahontan Basin.

It is not definitely known whether Lake Surprise, in its extended condition, overflowed into Lake Lahontan. The apparent absence of any shore lines above the one just described possibly suggests that it did not. The clearness of that line, however, means that for some reason it is the elevation of a long resting stage. With only the evidence to be seen in Surprise Valley one would undoubtedly come to the conclusion that the period of rest was determined by the elevation of the outlet to Duck Flat. With evidence furnished by the shore line in Duck Flat, however, the elevation of the connecting area seems to lose significance, and that area appears to have been a shallow strait, possibly covered by water but five or ten feet deep. For the explanation of the Duck Flat shore line one must turn either to a hypothesis of a long period during which evaporation balanced inflow or else seek to find an outlet for the extended lake.

The lowest divide between Duck Flat and the Lahontan basin, as shown on the Granite Range (Nevada) Quadrangle, has an elevation of 5,200 feet, or is 100 feet above the elevation determined for the high-stage shore line in Surprise Valley. This barrier would not seriously injure any hypothesis of overflow unless substantiated by a more precise survey because the topography and elevations of the quadrangles in northwestern Nevada are notoriously inexact. A deeply cut cañon leading south from the Duck Flat rim to Buffalo Meadows and from there connecting with drainage leading to a point near Round Hole, about thirty miles north of Sand Pass, in the Smoke Creek Desert of the Lahontan Basin, strongly suggests that it served as outlet for Lake Surprise.

With lowering waters the Duck Flat portion of the lake disappeared more rapidly than the Surprise Valley portion as evidenced by the fact that an outlet gorge was cut between the two, the gorge sloping toward Duck Flat. The first hundred feet or so of gorge-cutting was in basalt. Below the lava the stream encountered less resistant pyroclastic andesite into which it cut for as much as two hundred feet more. The entrenched meanders of the connecting stream are indicative of hesitancy on the part of that stream in cutting into the flat floor of basalt. During the period of gorge-cutting a delta, with a surface area of three or four square miles, formed at the Duck Flat end of the gorge. The gradient of the gorge and the elevation of the delta surface indicate that the detached Duck Flat portion of the lake stood almost two hundred feet lower than the level of the water body in Surprise Valley. The delta surface itself indi-

cates growth in lowering waters. Its upper portion is now deeply entrenched by both the main stream and a number of small tributaries but its lower portion, which is almost at the level of the floor of the basin, has suffered but little dissection.

When Lake Surprise was still two hundred feet deep, overflow into Duck Flat was cut off because shrinkage was proceeding so rapidly that gorge-cutting could no longer keep pace. Thereafter the Duck Flat portion of the lake probably soon disappeared, because it had been able to maintain itself at a shallow depth only when receiving the overflow from the north. As the main lake finally disappeared a small reversed stream formed in the northern end of the outlet gorge.

The salient features of the history of Lake Surprise have here been stated in terms of a general rising and lowering of waters. It is practically certain that an additional fluctuation in level caused the valley to be "nearly, if not completely, desiccated," as Russell pointed out. The salt zone in the lake sediments is a strong indication in point. The nearness of this zone to the present surface suggests that this event took place in Lake Surprise history. In this respect variations in level seem to resemble those worked out for Lakes Bonneville[5] and Lahontan.[6] Both of those lakes reached higher levels during their shorter, later, high-water stages than during their longer, earlier, high-water stages. The inability of Lake Surprise to rise above the level of its one very striking shore line suggests that it overflowed into Lake Lahontan during its supposedly earlier and protracted high-water stage. Further evidence of similarity to the outlines of Lake Lahontan history is to be found in the chemical history of Lake Surprise, which, while not carefully studied by the writer, seems to agree closely with Russell's observations as given in chapter 5 of the Lahontan monograph.

DESCRIPTION AND DISTRIBUTION OF SURFACE TYPES

Ten principal types of land surface are recognized in Surprise Valley and bordering range slopes. The approximate extent of each is indicated on the accompanying map, figure 4. Each of these types is usually susceptible of division into subtypes and to some extent these are suggested in the text. In several instances the boundaries between types, or subtypes, are sharp and can be mapped precisely. In other cases the boundaries themselves are gradations with but little

[5] Gilbert, G. C., U. S. Geol. Surv., 2d Ann. Rept., 1881, p. 186.

[6] Russell, I. C., U. S. Geol. Surv., Monograph 11, 1885, p. 237.

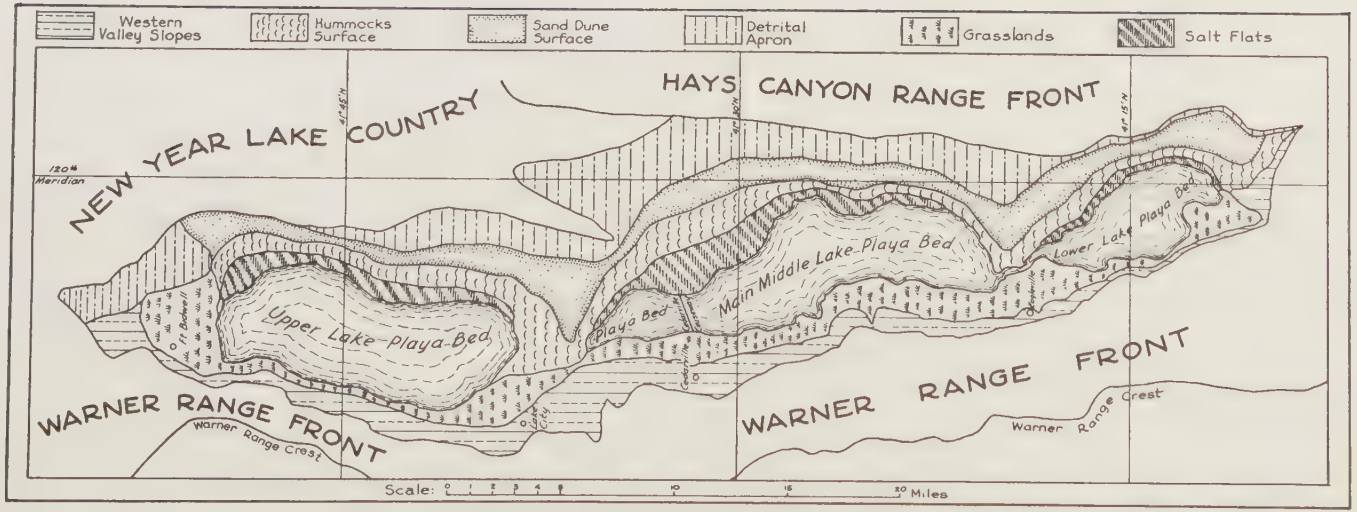

Fig. 4. Distribution of surface types in Surprise Valley.

significance and represent only transitional zones between distinctly different nuclear conditions. The salient features of the natural landscape in Surprise Valley and its borders are here called to mind but the distributional mapping is only very approximate and the descriptions are those of reconnaissance rather than of detailed study.

Warner Range Front.—Bordering Surprise Valley on the west is the abrupt steep escarpment front of a young and growing Basin range. The direction of this front is approximately north and south and, though it maintains that general strike persistently for its length as a whole, there are local sinuosities in its trend so that here and

Fig. 5. View southwest from a point about three miles south of Cedarville showing Warner Range front, range base, and typical vegetation of the Western Valley Slopes.

there salients project out into the valley for short distances. Between these are usually gently curvilinear and shallow embayments.

Between the range crest and the valley are numerous short, straight, parallel streams. Several of these are perennial but the great majority flow only at times of melting snow and during showers. Possibly one out of every four of the larger streams extends back as far as the range crest. These streams usually have several rather important tributaries in the summit areas where some are beginning to form headwater basins. Streams not reaching the crest are notably without tributaries other than short wet-weather rills which usually run straight down cañon sides. Typically each major stream runs down a steep V-cañon and is so spaced that it is separated from its neighbors by sharp crests. The even spacing of cañons and ridges

is shown in figure 5, a view taken a short distance south of Cedarville, in the central portion of the valley. In the vicinity of Eagleville, in the southern half of the valley, the range front is higher and the cañon walls more rugged. In that area gorges, such as the one shown in figure 6, are not uncommon and many of the streams flow over falls which, when dry, are impassable to a man on foot. Head-

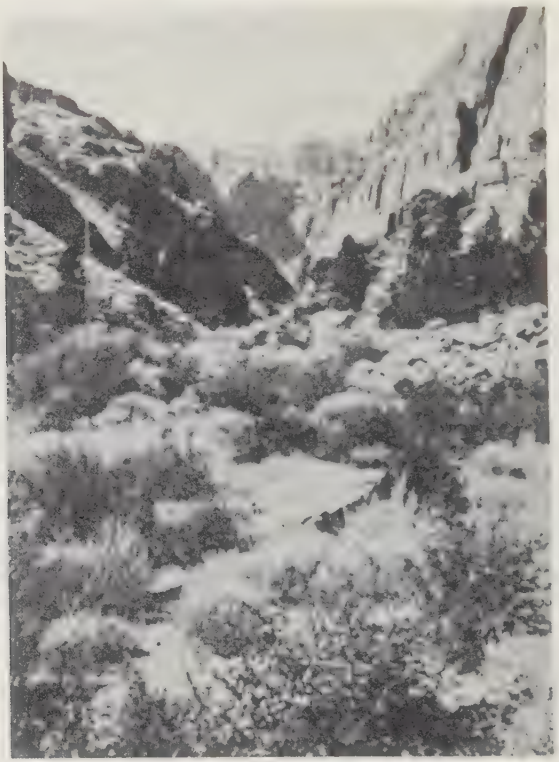

Fig. 6. Mouth of gorge of Eagle Creek, just southwest of Eagleville, quite typical of gorges in this part of the Warner Range front and showing topography and vegetation typical of alluvial fan heads.

water basins are more developed there than farther north. The walls of these are often so steep as to render them practically inaccessible.

In longitudinal profile the ridges between the cañons and gorges are greatly oversteepened at the base, where faceted noses border the valley. Some of these noses are slit by small gullies leading steeply downward to alluvial cones. Between the slits the noses are ordinarily covered for several inches or more by relatively coarse float, which slowly works its way down to form an alluvial apron at the range base.

Above their oversteepend bases the ridge profiles are influenced greatly by the westward dip of alternating layers of resistant and less resistant bedrock. Along these crests ordinarily a number of westward-dipping steps are separated by short vertical cliffs.

The vegetational appearance of the range front, as seen from the valley, is that of sagebrush with scattering juniper trees, the landscape shown in figure 5 being typical. From the range crest, looking downward, as in figure 7, one sees numerous stands of fir and yellow pine. At the immediate crest are lodgepole pines. In the headwater

Fig. 7. View of Upper Lake from Warner Range crest southwest of Lake City showing lodgepole pine in the foreground and stands of fir and yellow pine elsewhere on the range front. At this time the playa is shown as being nearly full of water with only a narrow dark strip indicating the "recede." The Salt Flats area is beyond the "recede" and is quite white. The New Year Lake country is in the distance.

basins there are bright green grassy meadows which are often kept green throughout the summer by springs. Groves of aspen in many places dot the meadows and everywhere above the elevation of 7,000 feet, or so, are alpine plants.

Only two regularly used automobile roads cross the Warner Range, one, centrally located, leading eastward to Cedarville and the other leading to Fort Bidwell, in the northern end of the valley. In addition, four wagon roads lead from valley to range crest. The step-like character of the ridges has eliminated ridge roads or even trails. Occasional trails lead up cañons to the crest, but, in the area west of Eagleville, for about ten miles the range front is so steep that there is not a single regularly used horse trail to the summits.

Western Valley Slopes is a term which will here be used to include the surface immediately below the range base and extending as far eastward as slope wash and alluvial fan materials are conspicuous elements of the soil. As thus defined this is a rather broad zone and is readily divisible into subtypes. The essential unity of the area is given by porous, well drained soil upon which the typical natural vegetational cover is sagebrush and in early summer a short bunch grass crop. Toward the base of the range junipers are scattered about on this surface. Near the streams the sagebrush is higher and at the sides of the channels cottonwoods and other trees are to be seen. Eastward the sagebrush is dwarfed and more widely spaced.

The deltas of Lake Surprise stand out from the remaining parts of the Western Valley Slopes not only because of their topography but also because of vegetational contrasts. Elsewhere near the range base juniper trees are fairly numerous but on the delta surfaces they are almost entirely absent. Sagebrush thrives on the deltas. It is closely spaced and individual plants are often four feet, or more, in height. Very little grass gets a foothold in the shadow of the sage. The vegetational cover of the deltas is certainly strongly influenced by the fanglomeratic nature of the surface and also by the drainage. Comparatively little attempt has been made to clear this land and introduce domestic crops. The sides of the deltas are often entirely barren and are used for road material.

At the mouths of all the cañons of the range front are the apices of alluvial fans. A few of the fans extend short distances up the cañons but recent faulting at, or near, the range base has defined the position of most fan heads. The fans slope eastward with upwardly concave profiles which become flatter toward the valley floor. Transit observations as to initial slope gradients, at the fan heads, gave results varying from 4° to 10° in more than thirty fans measured. Toward the eastern boundary of the Western Valley Slopes, the region of coalesced fan bases, profiles flatten out to as little as 15′ slopes, in extreme cases, and to less than 1° as a rule.

It is chiefly in the apical areas that fans stand out in contrast to adjacent parts of the Western Valley Slopes. Here, as shown in figure 6, coarse rubble and scattered boulders accumulate in floods. Indeed, boulders three or four feet in diameter are often swept out a half-mile, or so, from the range base. Sagebrush usually grows rankly at the fan apices, individual plants often exceeding six or eight

feet in height. Cottonwoods and wild plums occasionally establish themselves in this uncertain territory but often the immediate sides of stream channels are treeless.

Between the fan apices the abruptness of change of slope between the range front and the Western Valley Slopes is mellowed by the accumulation of slope wash from the ridge noses. Even so, as shown in figure 5, the boundary is quite sharp. The alluvial apron resembles the fans in regard to east-west profile. In both cases the profiles are an expression of sorting of sedimentary deposits, finer and finer materials composing the gentler slopes eastward. Locally at the range base the inter-fan areas are covered by small cones, with slopes of from 8° to 28°, and by accumulations of talus which weather out of layers of lava in the ridge noses and which usually stand at slopes of from 25° to 33°. The talus slopes are usually barren of vegetation, while the alluvial cones are rankly overgrown by tall sagebrush but are devoid of other plants. The remainder of the inter-fan area toward the range base supports junipers, often reduced to shrub size, and sagebrush of intermediate height, long stretches, for example, having no plants over three feet high. Much of this inter-fan area has been cleared for dry farming, wheat and rye being the principal crops.

Toward the valley floor the contrast between fan and inter-fan slopes decreases. The stream courses are usually semi-permanent in position, but nearly every stream in the valley has made one or more notable shifts since the valley has been inhabited by whites. During a flood, in 1909, for example, Eagle Creek abandoned a course on the north side of Eagleville and established its present course on the south side of town. Shiftings of streams are thus responsible for a condition of fan coalescence. The fan areas of today are often the inter-fan areas of tomorrow, hence no considerable contrast exists between the two. The surface for the most part is gravelly. The coarsest gravels are usually found in the present stream channels which commonly occur along fan axes. The north-south roads of the valley ordinarily have longitudinal profiles which are divisible into a number of upward convexities, each a fan, usually with a stream channel at its highest part.

The surface of the coalesced fan area is covered by sagebrush, rabbit brush, a plant known as "native tobacco," and short bunch grass, green in the spring but brown in the summer and fall. Cotton-

woods grow along the streams and occasionally one finds a clump of willows at some spring site. Much of this surface has been put under the plow for dry farming, the chief crops being wheat and rye, and occasionally barley. In its uncultivated condition the land furnishes good grazing for cattle and sheep. It is well shown in figure 5.

The whole of the Western Valley Slopes area is subject to breaks due to recent faulting. Usually the scarps are close to the range base but now and then they may be a mile, or more, removed from it. The scarps are ordinarily less than 50 feet high; between Cedarville and Eagleville, however, some were found to be as high as 125 feet. The fronts and bases of the scarps often support a growth of juniper trees or shrubs.

Grasslands.—Between the playas of the valley floor and the Western Valley Slopes is a comparatively broad belt of grassland surface. Toward the west the change to valley slopes is gradual but the eastern boundary of the belt is quite sharp.

The Grasslands area is better watered than is the area just west of it. In it are numerous springs, conspicuous in the landscape because of clumps of willows surrounding them. The bulk of the water here coming to the surface seems to have come from the Warner Range, having seeped into the fan apices, the alluvial aprons between fans, and into stream channels themselves, and from there flowing downward, so far as is known, in definite channels, through the porous materials underlying the Western Valley Slopes to be forced to the surface on encountering less pervious materials in the Grasslands. Near Lake City some of the springs bring rather large amounts of fine silt to the surface and build small mounds at their vents, objects known locally as "mud volcanoes." Hot springs also occur in the Grasslands and immediately to the west of them. Near Lake City some of these bring enough marsh gas to the surface to be ignited, an unfortunate fact for the valley as it causes periodic interests in oil prospects. Each "boom" drains a rather considerable amount of money out of an already heavily mortgaged and not too prosperous farming community.

Gravel is ordinarily absent from the Grasslands soil. The area is sufficiently removed from the range base to be beyond the belt in which alluvial fans play an important rôle either topographically or from the standpoint of sedimentation. Most of the Grasslands surface is subject to flooding but the waters have little or no velocity so that the size of deposited sediment is very fine.

The transition from Western Valley Slopes to Grasslands is accompanied by a gradual dwarfing and wider spacing of sagebrush and the coming in of a more uniform cover of grass, less bunchy in character than that of the slopes. The sagebrush disappears entirely from the typical Grasslands and the grass remains green through most of the summer. Locally, below some of the springs, it is green all summer through. Some of the springs maintain channels leading the entire distance down to the playa beds of the valley floor and these are flanked by strips of greenness throughout the dry season. Ordinarily, where not in a position to receive drainage from springs, the grass toward the playas again becomes bunchy in character.

The upper, or western, part of the Grasslands is the most valuable farming land in the valley. In addition to the cereal crops grown on the slopes it produces a great deal of alfalfa seed. Nearly all of this belt is now under cultivation. Roads run along most section lines and sometimes along half- and quarter-sections as well. Looking down from the range front or Warner Range summits, as in figure 10, this area stands out from the rest of the valley because of its checkerboard farm pattern. Clusters of farm buildings probably average one to the section, each typically surrounded by a clump of cottonwood or poplar trees. Rows of poplars, most commonly running along east-west lanes, still further place their stamp on the appearance of the cultural landscape of this area.

Toward the playas the Grasslands are chiefly of value for grazing purposes. This is the typical horse pasture of the valley. The unit pasture is usually a section. In one corner it ordinarily has an open shed to provide shade in the summer. In some of the fields wild hay is harvested and stacked, but the length of the grass is seldom sufficient to warrant cutting. Roads and farm buildings are more widely spaced in the vicinity of the playas; the fences separating pastures and the unequal grazing conditions impose upon adjacent fields, however, a checkerboard appearance hardly less striking than that of the area to the west.

Cold springs of the Grasslands are typically located in small depressions, usually from one to three feet in depth and with abrupt and fairly steep boundaries. The spring occurs near the upper end of its depression and near it the walls are usually steepest. Toward the playas the depression broadens, often to widths of one or two hundred feet, the walls are lower and less steep, and in a distance of a quarter of a mile or so the depression dies out.

Where animals are now allowed to graze in fields with unfenced springs it is apparent that they have much to do with the deepening and perpetuation of the spring depressions. The floor of the depression is typically a saturated bog with a surface roughened by trampling. Considerable amounts of mud are carried out of the depressions on the bodies of the animals and trampling in the bogs assists mud to be carried in suspension in slowly moving waters, flowing from hoofprint to hoofprint always downslope to the grassy surfaces below. It is natural that some running water erosion should

Fig. 8. Menlo Baths, about four miles south of Eagleville, showing a hot spring, with its little cirque-like amphitheater, now dammed and converted into a pool. In the flat at the right is a typical marshy Grass-lands surface. The southern playa is shown in front of a portion of the Hays Cañon Range front.

result from a flowing spring. Were it not for the influence of animals this erosion ordinarily would be confined to a relatively narrow strip, the channel of the flowing waters. Trampling obscures this channel, or rather transforms it into a broader zone, and it also speeds up the rapidity with which the erosion takes place because each time mud is agitated it is helped on its downslope journey.

Numerous depressions similar to those just described do not now contain springs. That they have done so in the past is often indicated by their arrangements in lines, usually in line with flowing springs, an arrangement which is typical because of the control of spring locations by recent faulting. The extinction of these springs might possibly reflect climatic change but it seems probable that the compacting of ground by trampling has had much to do with it. The freshness of many of the dry depressions suggests that extinction is of

very recent date and in all probability is to be associated with the settlement of the area by whites.

Some of the hot springs, particularly those south of Eagleville, are large enough to give rise to streams several feet wide. One of these, very near its source, is shown in figure 9, and one that has been artificially dammed in order to convert it into a swimming pool is shown in figure 8.

Weathering takes place rapidly around the hot spring vents. As the vents are ordinarily located on fault scarps, the rapid weathering tends to drive them back into the scarps with the result that comparatively small, cirque-like, steep-walled amphitheaters come to mark hot spring sites. The flooded amphitheater shown in figure 8 is to some extent artificial but for the most part was developed by the natural recession of the spring from an original site on a scarp approximating in position the present dam.

In regard to the location of hot springs on fault scarps it might well be argued that recession into the scarps would be impossible. This would probably be true if the waters ascended along the faults near which they emerge. In the territory south of Eagleville, however, this does not appear to be the case. There are usually a number of recent faults between the range base and the main floor of the valley. Water appears to ascend along faults near the range front and then to flow along pervious strata downward to the Grasslands. As the previous strata are frequently truncated by recent faults, and exposed on their scarps, it is on the scarps that the water is most likely to emerge at the surface. It is usual to find several individual vents arranged horizontally along some one particularly porous layer.

For some distance below the vent the waters of a hot spring often flow in well defined channels. This condition is shown in figure 9. In some cases these channels are steeply walled and depths of ten feet are not uncommon. Though not subject to flooding, the little hot spring streams erode rapidly and the ordinary agencies of valley development often cannot keep pace with them, hence their steep walls. After a comparatively short course through its miniature gorge each stream typically spreads out into a boggy area. The gradient of the bog is often approximately the same as that of the channel above. In the bogs there are usually several distinct and often anastomosing water courses. At the sides of the bogs are the continuations of the miniature gorge walls, usually in much reduced form both as to height and steepness.

The critical factor that seems to determine the upper end of the bog is the temperature of the water in the stream. Where animals are allowed to graze in these areas their footprints indicate that they walk and drink freely in the waters of the bogs but not in the gorges. Thus the spreading of the waters in the bogs seems to be a matter of zoogene erosion. Were it not for the animals which have grazed over the Grasslands for thousands of years, it seems reasonable to suppose that the hot spring streams would everywhere flow in rather

Fig. 9. A stream originating in a hot spring which has its vent partially in the area shown at the lower right side of the picture and partially in the area immediately beyond. Showing Grass-lands vegetation on the near side of the stream and Western Valley Slopes vegetation on the bank of the "miniature gorge" which has been cut by the stream. Another such bank exists to the left of the area included in the view.

distinct channels to the point where they end because of seepage or evaporation or, in the cases of the larger ones, to the playas below.

Playa Beds.—On most maps of Surprise Valley three large lakes are shown. These are often called "Alkali Lakes," often "Upper, Middle, and Lower Lakes," and sometimes these names are combined. Locally they are called the "Surprise Valley lakes," but the notion of three is often foreign to the minds of the inhabitants of the valley. The northern, or upper, lake is distinct and when filled is a unit water body. The middle lake was quite distinct and pretty much of a unit until a few years ago when it was divided in two by a causeway east of Cedarville. To some extent, however, the southern lake is an aggregate of smaller lakes and thus departs somewhat from the unification possessed by the other two. All the lakes are playas but all do not

become equally dry at the same time. As the waters of the larger lakes evaporate, so that isolated depressions alone remain filled, it is not at all rare to find that specific names have been given to these small "lakes." This is particularly true in the case of the numerous depressions usually mapped as "Lower Lake." Many of these basins contain particularly persistent lakes, some of which are not dry probably more often than once in ten or twenty years. Thus the term "Eagleville Lake" means much more in Surprise Valley than does the term "Lower Lake," and is used to mean a small portion of the

Fig. 10. View southward from Mt. Bidwell at the northern end of Surprise Valley showing Upper Lake, "recede," Salt Flats, Warner Range front, at the right, and to some extent the checkerboard appearance of the Grass-lands. At the left of the view is the New Year Lake country. In the foreground the forest is fir and the dark patches in the depressions are groves of dwarfed aspen.

latter, situated near the town of Eagleville, a water body which is said to have been dry only once in the memory of any of the inhabitants of the valley.

Upper Lake, when filled, is about thirteen miles long and four miles wide and is somewhat rectangular in shape. An overflow channel into Middle Lake prevents it from becoming of greater extent. In normally wet years it contracts to about half that size during summer but during the summers of dry years its waters disappear entirely. Fgure 10 is a photograph showing the lake almost full late in June, 1922. At the same time of year in each of the three following summers the lake had either disappeared entirely or else was reduced to a few small pools along its western margin. In winter the frozen

surface of the lake often serves as a highway between Lake City and Fort Bidwell. When completely dry the smooth playa floor is again used by traffic. Upper Lake, however, does not become as completely dry as the lakes south of it and it is usually with considerable risk that one attempts to cross its western borders in an automobile.

Middle Lake is nearly as wide as Upper Lake and is eighteen miles long. The northern four miles have been cut off by the Cedarville causeway. This part of the lake is only about half as wide as the average width of the southern part. The cut-off part of the lake is dry most of the time, particularly in summer when its smooth hard floor is excellent for automobile traffic. Each road leading to this part of the lake seems to be connected with every other road so that a pattern of tracks is established, which reminds one of the construction lines of a loxodromic chart. The main, lower, part of Middle Lake usually retains a considerable amount of water over its surface until early summer. Ordinarily one or two pools along its western margin persist the year through. In very dry years these disappear but the clay remains sufficiently moist to cause traffic difficulties. For this reason there are several well defined points of embarkation on the west shore and from these, roads to points on the eastern shore spread like the rays of an open fan.

Lower Lake has about half the length and breadth and a quarter the area of Middle Lake. Toward the south is the broad, continuous playa shown in figure 8 but farther north its continuity is broken, chiefly because of aeolian accumulations, and numerous, often isolated basins have formed within its limits as usually mapped. Nearly every year a certain amount of water overflows from Middle to Lower Lake through a winding channel which here and there spreads out into little basins of as much as five acres and which become small playas. In spite of waters received from the north practically all the individual basins in Lower Lake dry out each summer. However, even in the driest years a few depressions along the western side of the largest playa contain water from near-by hot springs. Houses are practically absent on the eastern side of Lower Lake and are rare on its western side. For this reason very few tracks are to be seen across its smooth floor. Such traffic as does exist between the two sides either takes a route around the southern end of the lake or else follows a road east from Eagleville and crosses the channel between Middle and Lower lakes.

In the main there is great resemblance between the various Surprise Valley lakes. All have dry periods, of greater or lesser length, and all are filled, or more properly covered, by a thin sheet of water or ice for a part of each year. When filled the shore lines migrate freely with changes in wind direction, the western shores being, however, somewhat fixed in position because of their steeper slopes. On account of their shallowness, depths of more than a foot being uncommon when fullest, practically no wave erosion takes place around the lakes. Even during the most violent winds the maximum height of waves is a foot or so at the most in the deeper parts of the lakes. In fact it is impossible to determine precisely the water's edge, so gradual is the transition from a film of water through a condition of greater and lesser dampness to actual surface dryness. The drying up of each lake is typically a matter of westward moving of the indistinct eastern water-line. Where the western border becomes absolutely dry the last stage of drying is simply the disappearance of a condition of surface dampness. It is not until the surface has been apparently dry for several weeks that it is safe to venture forth upon it in an ordinary automobile. To the inexperienced these playa surfaces are somewhat treacherous, particularly when entered from the east. Every surface appearance of dryness and hardness may exist and still one may find himself shortly in a tractionless sea of slippery mud. When thoroughly dry, however, that is, dry to sufficient depth that the weight of an automobile is no longer able to "break through," the smoothness of these floors is most inviting and one readily prefers them to the ordinary roads of the valley.

In detail the surface of the Playa Beds is a mosaic of irregularly outlined mud blocks, each presenting an irregular hexagonal pattern on the upper surface. The typical surface of each block is light in color and is hard and smooth, curled up somewhat on the edges, and is itself subdivided into smaller and similar hexagonal blocks. The upcurling of the edges causes some of the dry crust to be broken into small fragments, a process which gives rise to a white dust. Dust whirls are frequent in the summer and fine dust is so widely distributed over the Playa Beds that it is picked up to form whirls of a height of 1,000 to 3,000 feet. These elevations are readily ascertained by sighting across the top of a whirl from a known elevation on one of the bordering ranges to another known elevation on the other. Violent winds, most frequently blowing from the north, stir up great clouds of dust so that frequently at elevations of less

than 2,000 to 3,000 feet above the valley on one range the other range is wholly obscured from view. On a small scale dust originates in the tracks made by automobiles during the summer. A dusty track is soon abandoned in favor of a new parallel track on the firm floor at its side, with the result that all the main routes are characterized by many parallel and branching roadways.

The color of the Playa Beds is apparently the color of the lacustrine clay itself and is not directly associated with the presence of salt or alkaline substances. Mineral matter of this kind is certainly present in the clay but it appears to be quite evenly distributed, at any rate it is not sufficiently concentrated at the surface to cause whiteness. The comparative freshness of many of the playas and lakes of the western Great Basin may be an expression of this same condition. When the Surprise Valley lakes are full cattle drink freely.

Salt Flats.—Just east of the Playa Beds, and absent from intervening areas, there is a belt, with an usual east-west breadth of less than a mile or two, characterized by salt and alkaline crusts and efflorescences, and which may appropriately be called the Salt Flats. Strictly speaking, this belt is not flat but slopes gently westward; it appears flat in contrast with the hummock and dune belts east of it. The boundaries of the Salt Flats are very indistinct but the characteristic forms are so different from that of the areas on either side, and the area having this condition is so large, that it deserves special recognition.

The Salt Flats are not peculiar to Surprise Valley. They are developed elsewhere in connection with Great Basin playas and are described by Russell[7] in the Lahontan Monograph. In speaking of the origin and distribution of the efflorescences he states that:

> They originate in the saline lacustral clays which floor all the valleys once occupied by the ancient lake, and usually occur in greatest abundance on the borders of the large deserts, where they not uncommonly whiten the surface for many square miles. In tracing their distribution it is noticeable that they occur most abundantly in those portions of the valleys that are underlain by clays deposited directly from suspension in the ancient lake, but are not found on the surfaces of many of the more modern playas which occupy the lowest depressions in the various basins, thus showing that the recently formed playa-beds are in many instances less saline than the true lacustral clays.
>
> The genesis of the efflorescent salts that appear on the desert surfaces is not difficult to explain. During the rainy season the clays become saturated with moisture, but on the advance of summer they dry at the surface at the same time that moisture rises from below through the action of capillary attraction. The

[7] Russell, I. C., U. S. Geol. Surv., Monograph 11 (1885), pp. 230–31.

waters saturating the beds are rendered saline by the salts they dissolve from the clays, and on evaporating at the surface deposit all foreign matter as a surface incrustation. The incrustations thus formed are frequently five or six inches in thickness. They frequently dissolve and disappear during the winter, only to reappear when the heat of the summer dissipates every drop of moisture from the surface of the deserts.

It is not by any means certain that Russell's simple explanation for the presence of incrustations and efflorescences is tenable. Possibly it is. The present writer cannot settle the question in the light of his own observations but he has difficulty in seeing why capillary attraction does not raise saline material through the relatively thin veneer of playa clay. If it be argued that the playa clays are not so thin, then, at least, their marginal areas are thin. In these areas, so graphically called "the recede" in Surprise Valley, efflorescences are absent.

The distribution of incrustations and efflorescences given by Russell is strikingly similar to the distribution in Surprise Valley. They are around the playas, not in them. In Surprise Valley the critical westward limit of this Salt Flats condition seems to be the uppermost limit of covering by water. On account of the shiftings by the wind, the high-stage shore lines of the existing lakes are indistinct but they seem to coincide perfectly with the limit of the whitened area. In any explanation of the origin of these surface salts it seems as if this must be a critical factor. Possibly the explanation by Russell takes this into account for the playa clays are certainly not being deposited beyond the high-stage shore lines.

Though it is largely speculative and unchecked by careful work, the writer cannot refrain from entertaining the possibility that the efflorescences of marginal areas are long-time accumulations, that the amount which rises each year is comparatively small, that the playa waters dissolve the annual accumulations which rise on their floors, concentrate them as the waters disappear, leave them in a condition quite unlike that which they had when at the ends of capillary tubes, and that in this condition they are blown away by the wind, with dust, and hence out of the playa floors. This might also account for the lesser salinity of modern than of more ancient clays and might possibly have something to do with the comparative freshness of many of the playas themselves.

There seems to be little evidence that the efflorescences of the Salt Flats are carried away in any noticeable amount by the wind. On the contrary, the minutely irregular surfaces of the salt accumulations

appear to be good dust traps. The whole Salt Flats area appears to be one of aeolian deposition at the present time. Digging into this surface one finds that for some depth he encounters incoherent dust cemented by salts in its upper few inches.

Aggradation of the Salt Flats seems to be due in part to irregularities in the structure of the efflorescences themselves. They coat the surface in the form of a puffy-appearing crust, which superficially seems to be light and looks as if it might readily be carried off by strong winds but which on closer examination is found in reality to be hard and firmly cemented to the ground. This crust appears white, or light colored, at some distance but when examined at close range is found to be somewhat darkened by accumulated dust. The dust is apparently trapped by the surface unevenness and remains there between crystal aggregates and in interspaces in the efflorescences.

On a larger scale the Salt Flats area has another type of surface irregularity which assists, or possibly is the major factor, in dust accumulation. Sun cracks, such as exist in the Playa Beds surface, are only inconspicuously developed in the Salt Flats. Here, in an arid climate, in an area which is almost wholly free from any sort of flooding, a relatively stable surface exists. Footprints last for several years, as do wagon tracks, or other disturbances of the surface crust. Almost all of it has been altered by the trampling of animals, particularly of cattle. An individual hoof mark is not only a depression but it also means the breaking of the surface into several irregular slabs, each typically tilted inward toward the central depression. Though the density of large animal population may have been somewhat less before the white man appeared on the scene, it was even then probably great enough to keep this surface in much its present condition. The upturned slabs are efficient dust catchers, as can readily be seen by looking underneath one and seeing the recently trapped material.

If there be anything in the notion that salt is being blown off of the Playa Beds it is possible that it considerably enriches the salinity of the Salt Flats as some of it would undoubtedly be trapped along with the dust.

Vegetation is absent from the typical Salt Flats. At a distance the surface appears whiter than the Playa Beds. In figure 7 the lake is shown mostly filled with water, the "recede" is a narrow, darker strip, and the Salt Flats, to the right, are distinctly white. In figure

10 a similar condition is shown, the "recede" being only one-fifth or one-sixth the width of the Salt Flats. In greater detail the surface is shown in figure 11 as the flat space between the hummocks. It is partly because of the absence of vegetation that the area appears so white at a distance. In the hummocky area just east, the Salt Flats condition persists, as shown in the figure, but the scattered vegetation on the little mounds is sufficient to give a somewhat darker appearance to that area, particularly when viewed from a distance.

Moderately used natural roads in the Salt Flats are fairly good. It is with great difficulty that the initial tracks of an automobile are

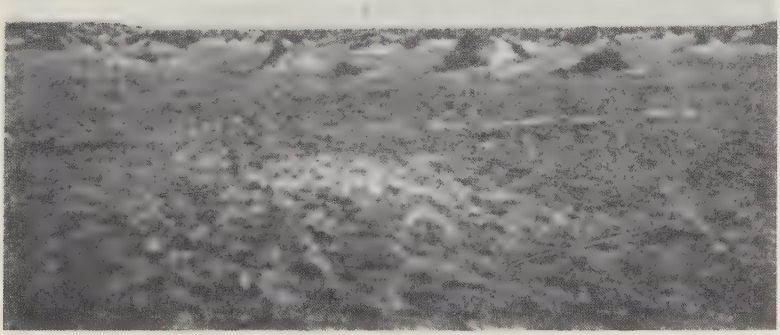

Fig. 11. Hummocks and Salt Flat surface east of Cedarville. The camera was pointed toward the southwest.

made, because of the necessity of breaking the upper surface. With some use the tracks pack down into a fairly satisfactory condition, but with anything more than moderate use, which in this area would mean possibly three or four trips a week over the road, ruts form and grow to depths greater than the clearance of most machines. As the ruts are often filled with dust for several inches this unevenness is often not apparent beforehand. As a result of these conditions the typical main road of the Salt Flats has several tracks, but not so many as the road of the Playa Beds, and ordinarily all tracks are in a bad state; indeed, it is nearly impossible to use them.

Farther toward the hills or range east of the valley, where the gradient is steeper, the occasional rains frequently turn the ruts into ravines, often six or eight feet deep, but the Salt Flats condition dies

out as the condition of steeper gradient comes in, so that generally speaking the ruts of the Salt Flats owe their depth almost wholly to traffic wear.

Hummocks Surface.—Hummocks (fig. 11) occur along the eastern side of the Salt Flats. They are widely spaced toward the west and the individual mounds are only a few inches in height. Eastward they increase in size to a maximum of six feet or so and accompanying this change the spacing, which at the start possibly averages one hundred yards between hummocks, becomes closer so that finally the mounds are but one hundred feet, or less, from each other and the total area of mound surface is probably ten times, or more, the between-mounds area.

The most striking difference between Hummocks Surface and Salt Flats has to do with the presence of the hummocks themselves. At the west the transition is very gradual. The Salt Flats condition continues into the Hummocks Surface between the mounds for a considerable distance eastward. Toward the middle of the Hummocks Surface one notes that the thickness of salt incrustation is less and farther east the area between the hummocks is covered by fine silt derived from the adjacent hummocks, washed down in time of rains.

The hummocks appear to be aeolian accumulations of sand and dust. They are certainly not erosional remnants composed of lacustral clay. No sign of uniform stratification is to be seen in digging into them. It appears that the trapping of dust and sand by the vegetation growing on the mounds accounts for their growth. As a matter of fact all stages of hummock growth are to be seen in the area.

Pioneering plants, probably some kind of salt sage, now and then manage to get foothold between hummocks. Around these, particularly on their southeastern sides, are small mounds of dust and sand. At first the dust and sand are quite unfixed and shift around the plants to their lee sides. Later other plants are established on the aeolian accumulation and the position of the growing mound becomes fixed. From such beginnings hummocks grow in size to the observed maxima. The characteristic size variation across the belt indicates that the eastern hummocks are older. As the western edge of the belt is now an area characterized exclusively by pioneer plants, this suggests that the condition of Hummocks Surface is advancing over the Salt Flats. Probably the original spacing of the eastern hummocks was similar to that of the western hummocks today. Where the Hummocks Surface is well established pioneering results in closer

spacing. Once a mound is established it is from then on a favorable site for vegetation, as evidenced by the fact that no mounds exist that do not have plants on them. The typical mound plant is sagebrush.

Sand Dunes Surface is found east of the Hummocks Surface and to some extent between the larger lakes. The dunes are distinctly related to the increasing slope of the floor upon which they rest and do not occur on slopes of less than 2 or 3 degrees, possibly an expression of friction. This is a condition which makes for depositional sorting such as can be observed in the apparently uniform grade size of the sand. Dust carried thus far is either deposited on still steeper slopes or else is completely removed from the valley. Unlike the hummocks the dunes do not depend on vegetation for trapping sand. The western front of the dunes belt is quite barren of vegetation.

The highest dunes are on the western side of the belt and usually do not exceed thirty feet in height. These dunes are in active migration. Toward the east they are lower and, judging from their vegetational cover, are firmly fixed. The ordinary road from Nevada to Middle Lake leads off through the Sand Dunes Surface, then winds around the hummocks, crosses the Salt Flats, and enters the smooth floor of the playa. Coming from the east it is a not uncommon experience to find that after winding through the eastern dunes for a mile or so the road suddenly disappears beneath a new dune twenty or thirty feet high, a mere hundred yards or so from a perfectly good road ahead. Often this experience comes to one who has traveled the same road without a bit of difficulty a month or so previously.

The irregular outlines of individual dunes reflect the variability of wind directions obtaining in the valley, but the prevalence of northeast-southwest crest-lines, with the steeper slopes eastward, indicates a predominant southeastward migration. The absence of dunes from the northern and western sides of the valley substantiates this view. By reputation, the prevailing winds are from the west. The prevailing storm winds, however, are from the north and a greater elevation for the Sand Dunes Surface in the southern end of the valley has resulted from this. The actual migration of dunes appears to be toward the southeast, the resultant from the two wind directions considered. As the western dunes are unfixed and those to the east are relatively fixed, sand at the western side of the belt migrates toward

the south relative to the dunes to the east. This, in addition to variability in wind direction, makes for uneven and non-uniform crest-lines.

The general tendency for Great Basin sand dunes to migrate southward under the influence of storm winds is strikingly shown at several places in northwestern Nevada. Just south of Surprise Valley, the dunes in Duck Flat are found mostly on the south side of the basin and have migrated up the slopes there to the summit between Duck Flat and Buffalo Meadows drainage, a fact which seriously adds to the difficulty of solving the problem of possible overflow of Lake Surprise in that direction. At the southern end of the Smoke Creek, or Blackrock Desert, the dunes also extend to the summit of the basin, at Sand Pass, on the Western Pacific Railroad, and again testify to the carrying ability of the north wind. The presumably prevailing west wind blowing at lesser velocities has been unable to produce any such striking effects in regard to sand distribution as has the occasional storm wind from the north.

An interesting minor feature of the Surprise Valley dune area, and one which in all probability is to be found elsewhere, results from the blocking of drainage from the Hays Cañon Range. Some of the larger streams, such as those coming from Bull Creek and Hays cañons, collect flood waters frequently enough so that they ordinarily maintain channels that reach the playas. The smaller streams, however, have smaller drainage basins, therefore they less frequently catch the waters from thunder storms, which are always small in their areas of greatest intensity. Owing chiefly to the lessened frequency of floods, these streams are usually unable to maintain channels across the dune belt. These channels often end as abruptly as dune-covered roads. Blocked channels remain unopened unless there is most severe flood, and ordinary stream flow results in the forming of little ephemeral lakes. In the eastern part of the dune belt a number of these lakes are permanent and lake sediments have collected in some of them to depths of ten or fifteen feet. As the floors of these lakes are ordinarily dry, free from vegetation, and wind-swept, dust and sand are carried off of them, leaving gravel and grit behind. These surfaces stand out in considerable contrast to the surrounding dune sands not only because of their flatness but also because of difference in coloration. The dune sand is light but the lake floors are dark because they are covered by rocks derived from basalt and dark colored andesite in the Hays Cañon Range.

When the small lakes in the dunes are drained their outlets lower rapidly and the sediments are soon eroded into miniature bad lands. The stratification of these deposits, as well as their surface form, causes them to stand out in considerable contrast to the surrounding dunes. When deeply dissected, the thickness and amount of fill in a basin of this type is readily measured, as the contrast between aeolian sand and stratified lake-beds is striking.

Whereas lakes form now and then in the migrating dunes area to the west, they are not particularly striking because of their impermanence. The shifting of dunes has more to do with the temporary nature of the small lakes than has the overflowing of basins.

Grass often grows along the stream channels in the dunes area and along several streams retains its greenness throughout the summer. This is a meadow condition restricted to flood plains, which ends abruptly at the sandy slopes. Cattle graze freely in these little green patches and walk over the dunes between them with sufficient frequency to keep most of the sandy surface roughened by the sinking of hoofs into the sand. In the area of fixed dunes they often establish well beaten trails across the more stable surface there.

Detrital Apron.—Between the Hays Cañon Range Front and the Sand Dunes Surface there is a surface, formed for the most part by slope wash and the coalescence of alluvial fans, which may appropriately be called the Detrital Apron. This surface resembles the Western Valley Slopes closely but differs from that area in several respects, chiefly due to the diminished rainfall of the area east of the Warner Range.

Because of the dominance of thunder-shower precipitation, element for element the slopes of the Detrital Apron are steeper than those in corresponding position across the valley. Alluvial fans very commonly start out with gradients of more than 10°. The inter-fan areas are almost as steep, so that, generally speaking, there is less contrast between fan and inter-fan areas than exists below the Warner Range Front.

There are practically no juniper trees on the Detrital Apron, the sagebrush is more widely spaced and more dwarfed, as shown in figure 12, and along the streams there are fewer cottonwoods. Hot springs are about as numerous along the base of the Hays Cañon Range as they are on the other side of the valley but cold springs are notably fewer. It is usually only at and below the sites of hot springs that any attempt has been made at clearing the land and

introducing domestic crops. Only a half-dozen houses or less are now occupied in the whole area and these are at hot springs. In one case, northeast of Cedarville, one of the springs has been utilized for bathing purposes. Bunch grass, growing between the sagebrush, furnishes fair grazing for cattle and sheep. Along some of the stream flood plains, particularly toward the base of the slopes and in the first part of the dunes area, some grass is cut and used as wild hay but usually the grass is not of sufficient length to warrant this use. The limited grasslands of the flood plains on this side of the valley are really the counterpart of the Grasslands on the western side of the valley. These areas are not mapped or given special consideration in this paper because of their limited extent and relative unimportance in the Surprise Valley landscape as a whole.

There are relatively few roads in the Detrital Apron area. The main roads run north and south and from these are branches, westward to the playas and eastward, for short distances, into cañons of the Hays Cañon Range. One of the east-branching roads reaches the range crest. This is the continuation of the road crossing the connection between Lower and Middle lakes, east of Eagleville, and it runs up Hays Cañon to a summit spring. The road crossing the Cedarville causeway is the main route into northwestern Nevada and southeastern Oregon from Surprise Valley. This road passes up the detrital apron near its northern end and leads into 49 Camp Cañon, just north of the Hays Cañon Range. There is considerable travel on this road and it is usually in rather poor condition. The other roads of the Detrital Apron are traveled but little and are usually in good shape. The chief obstacle in the way of using these roads is in the form of arroyos cut at times of downpours. An arroyo across the road usually leads to the discovery of a new track and the abandonment of the parts of the road in the immediate vicinity of the newly formed gully. The abandoned parts of the road appear to be better traveled than does the new track so that, unless one is very cautious and possesses a sense for picking the track in use, his first trips over the roads of this area will be accompanied by many little detours to arroyo banks. The conventional practice of placing sagebrush or stones across the abandoned part of the road is at times followed and any such signs should be given very careful consideration.

At the southern end of the valley the Detrital Apron is relatively narrow and the range front makes a sharp angle with the valley floor.

In the past it is almost certain that the large southern playa hugged this slope closely but now, by aeolian accumulations, the waters are restricted to a more central position in the valley.

Recent fault scarps are numerous on the Detrital Apron and resemble closely those on the western side of the valley. The main shore lines of Lake Surprise are higher, being situated on the range front itself.

Fig. 12. Hays Cañon Range front, east of Cedarville, with a portion of the Detrital Apron showing characteristic vegetation. The white areas at the range base are bad-lands eroded in andesitic tuff and agglomerate. The scar at the crest in the center of the view was formed as a result of a large slide. The irregular topography beneath is typical slump and slide surface.

Hays Cañon Range Front is steeper, more barren, and is characterized by a greater amount of conspicuous slumping than the Warner Range Front. The view shown in figure 12 shows the front east of Cedarville and is characteristic of the front as a whole. Bad lands tend to form in readily eroded pyroclastic rocks near the range base. Large scars from slumping and sliding are characteristic of the higher portions of the front. Beneath such scars are surfaces irregular in topographic detail and typical of slipped areas of this kind. The trees of the range front are mostly junipers but groves of dwarfed aspen are to be found in ravines toward the crests. Practically the whole surface is covered by sagebrush.

The differences between the Hays Cañon and Warner Range fronts are primarily expressions of difference in climate. The stratigraphic sequence of the two ranges is the same. The Warner Range owes its

topographic and vegetational differences primarily to the greater amounts of precipitation, particularly of snow, that fall upon it.

Using Köppen's criteria of climatic classification, the boundary between Humid and Dry Climates passes through Surprise Valley a few miles east of the base of the Warner Range. Cedarville is just on the humid side of the boundary and Fort Bidwell, situated slightly farther away from the range base and in the lee of lesser summits, lies just on the dry side. All the Nevada stations, farther east, are distinctly dry in regard to climate.

The vegetation, particularly the forests, of the westward slope of the Warner Range indicates that that area receives considerably more precipitation than does the eastward slope. In proportion to drainage area more water flows to the west than to the east, as shown by stream flow, spring flow, and the contrast of ground-water conditions on the two sides of the range. Goose Lake, on the western side of the range, is said to have been completely dry but once in the memory of Indian legends, whereas the large lakes east of the range are all playas.

The Warner Range is certainly a factor in increasing precipitation but this effect is not confined entirely to its westward, or windward, slopes. Precipitation increase, due primarily to adiabatic cooling of air forced up the westward slopes, affects the eastward slopes as well and also the valley near the range base. This is shown strikingly in tracing the Dry-Humid boundary either north or south. It swings westward in both cases, for in both directions the range dies out and lower elevations are found toward the west. Aside from the effect of augmenting the precipitation immediately to the east of its summits, the Warner Range casts a large rain shadow over the area east of it. The mean annual precipitation at Alturas, just west of the range, is 12.65 inches and that at Cedarville, in the zone of precipitation augmentation, is practically the same, 12.88 inches. The nearest station east of Surprise Valley clearly shows the rain shadow effect. Though less than thirty miles from Cedarville and nearly 1,000 feet higher, Vya, in Nevada, has averaged but 9.51 inches.

The eastern limit of precipitation augmentation appears to approximate in position the western boundaries of the playa lakes in Surprise Valley. Rain shadow conditions are certainly well established in the Salt Flats area and from there east. The summits of the Hays Cañon Range are only slightly less lofty than those of the Warner Range but, though the separation is only a matter of from twelve to eighteen

miles, locations that would be forested with fir, or at least yellow pine, in the Warner Range support only sagebrush and scattered junipers in the Hays Cañon Range. The snowbanks that last the entire summer through on Warner Range summits have no counterparts on the other range.

The large slump and slide surfaces of the Hays Cañon Range stand out as one of the most conspicuous features of its western front. These seem to result chiefly from insufficient vegetational cover for the maintaining of steep slopes. It is true that the attitude of the rocks of the range front is not such as to be especially effective in preventing slides and slumps, the rocks being almost horizontal, and it might be argued that the westward dip of the rocks of the Warner Range Front accounts for the absence of striking slumps and slides in that area. At the ends of the Warner Range, however, these features do occur and the topography resembles closely that of the Hays Cañon Range Front in spite of westward dips. In these terminal areas the summits of the Warner Range are lower and the vegetation also resembles that of the Hays Cañon Range Front so that deficient precipitation and less effective plant cover seem to condition the slide and slump areas in spite of unfavorable rock structures. As far as stratigraphic sequence is concerned, it favors sliding and slumping in both ranges, as has been pointed out by the writer in a recent paper.[8] Numerous slides of small size occur in both ranges. The contrasts here emphasized are those of major importance in the natural landscape; specifically those which are striking in fairly distant views, as, for example, in the view of one range from the summits of the other.

The shore lines of Lake Surprise, where not erased by slump or slide, or bad lands erosion, are usually somewhat more distinct on the Hays Cañon Range Front than on the Warner Range Front. The high-stage shore line, here as elsewhere, stands out particularly clearly as a contour a short distance above the range base.

New Year Lake Country resembles the Hays Cañon Range Front, to the south, excepting that summit elevations are somewhat lower and the simplicity of a single fault zone at the range base gives way to a complexity occasioned by a more or less crisscross arrangement of faults from two different major structural lines of displacement.

The scarps of the fault at the base of the Hays Cañon Range face westward. East of Lake City the range front loses the simplicity that

[8] Russell, R. J., Univ. Calif. Publ. Geog., vol. 2 (1927), pp. 231–54, pls. 26–29, 4 figs. in text.

characterizes it farther to the south, fades out rapidly as far as elevation is concerned, the main fault branches, fan-like, and numerous small scarps, each facing westward, dominate the scene. At, and some distance north of the head of Surprise Valley, branches from the Surprise Valley fault which farther south outlines the base of the Warner Range, give rise to a shingle-like topography of small tilted blocks, each with a scarp facing eastward. Between these relatively simple conditions the territory is characterized by both east and west scarps which cut it into numerous small horsts and grabens. Many of the blocks thus defined are more or less lozenge-shaped and their summit areas are tilted in varying directions. This is the typical structure of the nucleus of the New Year Lake Country.

As most of the scarps in the New Year Lake Country are low the exposed bedrock is mostly the basalt which regionally caps the andesitic pyroclastics. Slump and slide topography do not have much chance to be developed in the low lava faces of these scarps.

The vegetation of this area is practically that of the Hays Cañon Range Front but is more sparsely distributed. There are fewer junipers here and from the valley one sees very few groves of aspen. The shore lines of Lake Surprise are not plain in this area partly because of original feeble development on gradual slopes, for this was the main low water area of the whole lake, but more important than this is the fact that such traces of lines as do exist are largely obscured by drifting sand. The gentle gradients of some of the slopes to the valley permit eastward migration of sand to far greater distances here than elsewhere along the valley borders. The location of the area at the northern end of the valley is the principal reason that an extensive dune field has not covered large parts of it. As it is, dunes of fairly good size flank its lower margins and smaller dunes and sheets of sand are scattered about on many of the slopes.

Very few people are living in the New Year Lake Country and these are sheep and cattle-raisers. Ten years or so ago an unsuccessful attempt was made at settlement on an agricultural basis. A Modoc City was projected, the site to be approximately ten miles south of the California, Nevada, Oregon intersection. It is said that several hundred people in the Middle West were attracted by the project but, chiefly owing to the absence of a sufficient quantity of water, the attempted occupation was very short-lived and today hardly a trace of it remains.

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THE HISTORIC GEOGRAPHY OF TUCUMAN

BY
OSCAR SCHMIEDER

THE EDAPHIC ELEMENTS

In northwestern Argentine the lowland is surpassed by numerous isolated mountains. These *Sierras pampeanas*[1] are uplifted parts of the Brazilian shield. In their typical form they are tilted blocks (*Keilschollengebirge*), the steep slope of which is directed toward the east. Extensive old peneplains are frequently to be found at high elevations on these blocks, such as the Pampa de Achala in the Sierra de Córdoba. As isolated mountain masses these sierras formed no obstacle to the expansion of human culture, even at a primitive stage.

The continuous lowland of northwestern Argentine not only surrounds the Pampean mountains, it also penetrates in numerous valleys into the very Andean cordillera. The great Andean valleys are largely structural, and to a much lesser extent due to the action of running water. They follow altogether the trend of the Andean structural lines. In the west they are more or less simple *Graben;* in the structurally more complicated northeast, they coincide largely with *Schuppen* of less resistant sediments. These valley landscapes open toward the lowland at the south and east, are making for a gradual transition of all geographic elements from the lowland in the east and south, to the cordillera in the west and north.

By far the largest part of northwestern Argentine lies well within the arid climates (fig. 1). The Cw[2] climate of the western Pampa just approaches its eastern borders (Córdoba). Toward the west, aridity increases rapidly and the BSwh climate passes into a real BWhw, which is predominant in the area. Prevailing high elevations make

[1] Rassmus, Rasgos geológicos generales de las Sierras Pampeanás, Boletín del Ministerio de Agricultura, Sección B, Geología (N. B., Buenos Aires, 1916).

[2] The symbols are those used by W. Köppen, Die Klimate der Erde (1923).

the desert climate of the interior still less attractive to man (BWk'w and BSk'w). There are but two minor areas in northwestern Argentine which receive a greater amount of rainfall. From the East Bolivian Front Ranges extends a narrow belt of higher rainfall south to Jujuy, and along the east slopes of the high Sierra de Aconquija extends a local Cw climate (City of Tucumán almost 1,000 mm.)

The natural vegetation largely reflects the climatic conditions. The BS climate still permits tree growth, rather of the type of *monte alto* (xerophile forest), which passes toward the interior, under the influence of increasing aridity, into *monte bajo* (thorn scrub).[3] The moister localities, especially along the east slopes of the Sierra de Aconquija, produce a much more luxuriant vegetation. Their mountain forests with tall trees and an abundance of epiphytes are of almost tropical aspect. These forests rise on the mountain slopes up to about 2,500 mm. where a narrow belt of alder trees forms their upper border line.[4]

THE CULTURE AREA

Within the extensive territory influenced by Peruvian culture, the area which is at present northwestern Argentine was not only physically distinct but its population was racially, linguistically, and, to a certain extent, culturally differentiated from the peoples of the neighboring regions. The pre-Columbian population accordingly recognized this areal individuality by employing a particular designation for the region. The term *tucuma*[5] or *tuquma*,[6] which was in use among them, was later taken over by the Spaniards as Tucumán. Their early documents mention the province of Tucumán or the "gobernación del tucumán, xuries y diaguitas que es en las yndias del piru."[7] Each of the first four governors introduced a particular name for the area, none of which, however, found lasting acceptance. Nuñez de Prado called it *Nuevo Maestrazgo de Santiago;* Aguirre,

[3] Cf. Univ. Calif. Publ. Geog., vol. 2, pp. 259–261 (1927).

[4] Schmieder, O., Contribución al conocimiento del Nevado de Chani y de la Alta Cordillera de Jujuy, Boletín de la Academia Nacional de Ciencias, vol. 27 (Córdoba, 1923).

[5] Garcilasso de la Vega, First part of the Royal Commentaries of the Incas, vol. 2, L. V., pp. 79–80 (Hakluyt ed., London, 1871).

[6] Pedro de Cieza de León, Travels of the author 1532–1550 contained in the first part of his Chronicle of Perú. Eng. trans. by Cl. R. Markham, chap. 107, p. 383 (London, 1864).

[7] Gobernación del Tucumán. Correspondencia de los cabildos en el siglo XVI. Documentos del Archivo de Indias, *publ. in* Colección de publicaciones históricas de la biblioteca del congreso argentino (Madrid, 1918).

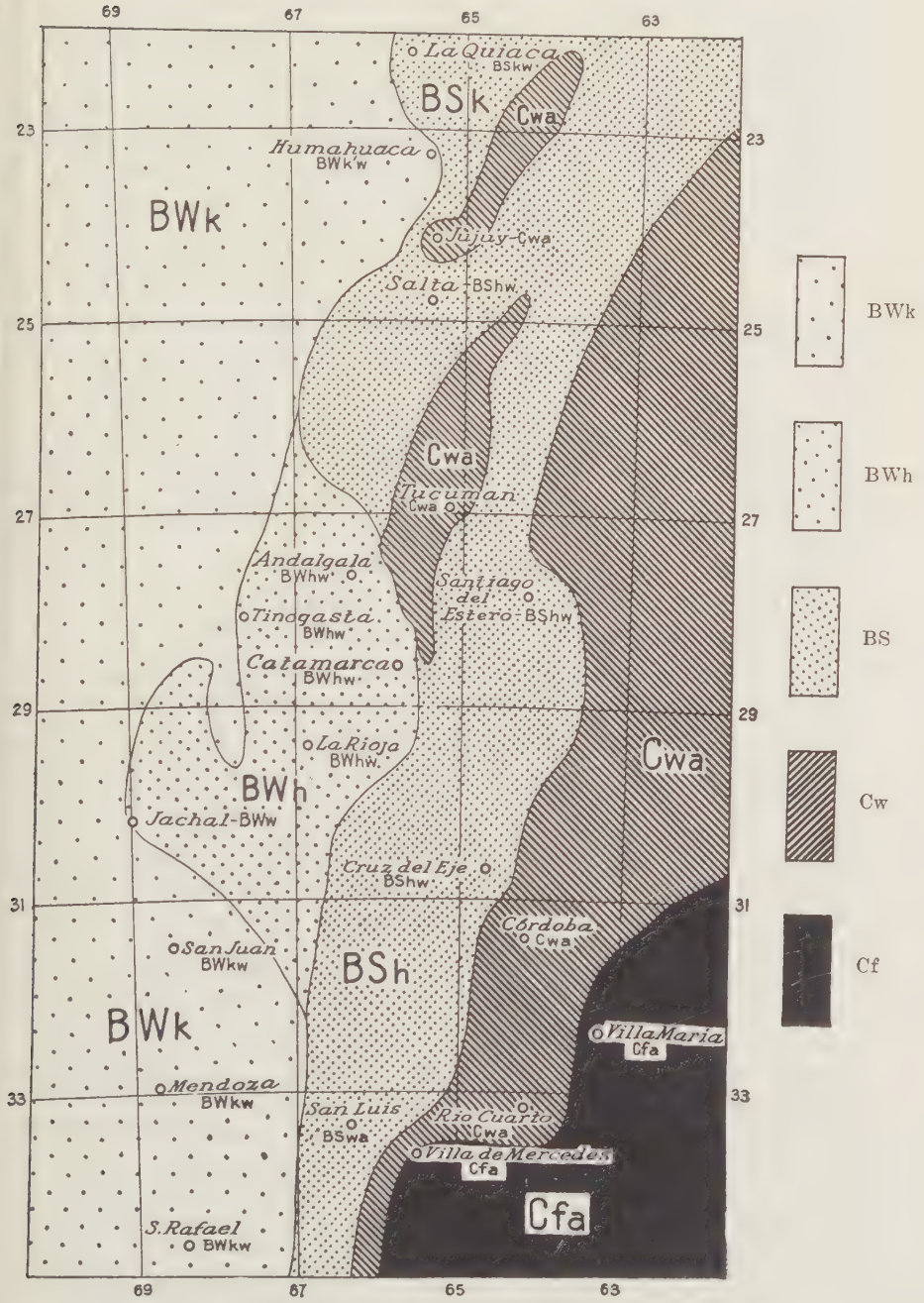

Fig. 1. The climatic areas of Tucumán.

Tierra de Promisión; Zurita, *Nueva Inglaterra,* and Castañeda, *Nuevo Extremo.* Nicolás del Techo gave the first, rather wide demarcation of the region.[8] During the disturbances following the war of independence, the *República Federal de Tucumán* arose (1820).[9] When the Argentine republic was formed, Tucumán received recognition in the old sense as "*las provincias de arriba,*"[10] the ancient name of Tucumán being applied to one of the modern provinces.

HISTORIC MATERIAL AS BASIS FOR A RECONSTRUCTION OF THE PRE-COLUMBIAN LANDSCAPE

Historic sources from the first decades of the Spanish conquest of ancient Tucumán are particularly poor. The meaning of the numerous ancient petroglyphs found in Ampajango y Andagualá in the valley of Santa María still remains enigmatic.[11] The region lacked gold and silver and its population was extremely warlike.[12] Furthermore, the small expedition of Nuñez de Prado,[13] who conquered the area in 1548–1550, proved inadequate owing to the fact that high prices in Perú had prevented his getting sufficient supplies.[14] Only with extreme difficulty did the conquerors impose themselves on the Indians; consequently, they almost perished of starvation.[15] None of

[8] Nicolas del Techo, Historia Provinciae Paraguariae Societatis Jesu, 1675. Liber 1, cap. 19, p. 15: "Tucumania inter Paraguarium et Chilenum regnum media, ab Oriente partim ipsi Paraguario, partim Argenteo flumini adjacentes terras nascipit, ab Occidente Peruviae montibus terminatur."

[9] Teran, Juan B., Tucumán y el Norte Argentino, 1820–1840 (Buenos Aires, 1910).

[10] Woodbine, Parish, Buenos Aires and the provinces of the Rio de La Plata, chap. 18 (ed. 2; London, 1852).

[11] Bruch, Carlos, Exploraciones arqueológicas en las provincias de Tucumán y Catamarca, Universidad Nacional de La Plata, Biblioteca centenaria, vol. 5, pp. 116–122 (Buenos Aires, 1911).

[12] Información levantada por el procurador del cabildo de Santiago del Estero entre los vecinos, Oct. 5, 1585, *in* Gobernación del Tucumán, *op. cit.,* p. 115: "gente guerrera astuta e yndimoniada que peleaban bestialmente por defender su tierra queriendo echar della a los españoles."

[13] *Ibid.,* pp. 114–115: "salieron de las provincias del piru con el dicho general juan nunez de prado sesenta hombres."

[14] *Ibid.,* p. 144, statement made by Captain Miguel de Ardiles, companion of Nuñez de Prado, 1585: "este testigo saue que las armas y caballos valian a quinientos e mill pesos los cavallos e yeguas e las armas muy caras y a excesibos precios e por esta rrazon los españoles no entraron en esta tierra con las armas e pertrechos que se requeria para gente tan belicossa como los naturales." The statement is corroborated by that of other eye-witnesses.

[15] *Ibid.,* p. 114: "La ganaron allanaron y conquistaron comiendo cigarras y langostas, yeruas, maizes, cardones, pieles de animales y otras cosas silvestres muriendo de hambre y sed bistiendo de cueros de venados crudos y otras rramas e yeruas."

them seem to have kept records as to the nature of the country as Cieza de León and Estete did under Pizarro. Neither was any attempt made by the early Spaniards to collect the traditions of the natives in regard to their past. This lack of historic source material is especially to be regretted since important changes seem to have taken place in ancient Tucumán shortly before the Spaniards arrived, an advance of the nomadic Indians of the plains having considerably reduced the area belonging within the Peruvian *Kulturkreis*.

On the other hand, in the study of the archaeology of the area much progress has been made. One of its most prominent students was the late Eric Boman, whose work is based on extensive field investigation of all the cultural remains of the ancient inhabitants of Tucumán, and utilizes all available historic sources which might help to interpret field observations. No other modern author provides the student of the historic geography of any part of ancient Perú with an equally rich amount of information.[16]

Vestiges of an Ancient Culture

Unique remains of an ancient native culture, destroyed long before the time that the Spaniards arrived, are still visible in the valley of Tafí, but no tradition is extant which might throw light on the people who sculptured here such remains as the *piedras paradas* of the present day *criollos*. These piedras paradas are *menhir*—like stone monuments up to three meters in height. The style of sculpture shows such likeness to that of Tiahuanaco that an early cultural relation with far away areas is suggested. Similar monoliths are known from the valley of Yocavil or Santa Maria. Besides ruins of numerous *pircas*,[17] remains of *andenes*[18] cover an extensive surface in the valley, indicating that in remote times a dense population, which belonged to the Peruvian *Kulturkreis*, cultivated the valley of Tafí, where abundant rainfall favors agriculture. No traces, however, of the settlements in which this ancient agricultural population of Tafí lived have been found up to the present.[19]

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16 Boman, E., Antiquités de la région Andine de la république Argentine et du désert d'Atacama (Paris, 1908), 2 vols.

17 *pirca*, Quichua term for walls built of uncut and uncemented stones.

18 *andenes*, Spanish term for agricultural terraces.

19 Ambrosetti, Y. B., Los monumentos megalíticos del Valle de Tafí, Boletín del Instituto geográfico Argentino, vol. 18, pp. 105 ff. (Buenos Aires, 1896). The first publication on the subject. *See also* Bruch, Carlos, Exploraciones, arqueológicas, *op. cit.*, chap. 1.

THE PRE-COLUMBIAN LANDSCAPE

Aboriginal population and its culture.—The first Spaniards to come to Tucumán found the population split into small political units, independent of the Inca empire[20] yet fully under the cultural influence of the Indians of the highlands of Perú. They were *gente vestida* and lived as the Peruvian Indians do, writes P. Sotelo de Narvaez, 1583, in his exceptionally good report on Tucumán;[21] and Boman states:[22]

> mes études des antiquités de la République Argentine m'ont amené à la profonde conviction que cette culture diaguite fait partie intégrante de la civilisation andoperuvienne, qu'elle émane presque entièrement de l'ancien Péru, sans plus différence entre les deux civilisations que celle qui existe entre l'éthnographie des divers autres parties de l'empire des Incas.

Yet this cultural unity did not preclude a noticeable differentiation in the types of their settlements and in their economic life.

The Spanish found by far the largest part of old Tucumán occupied by the warlike Diaguitas (fig. 2), who were divided into numerous tribes each of which inhabited one of the structural valleys and was politically independent. None of them had acquired sufficient power to subdue their neighbors.[23] They carried on warfare not only among themselves but especially with the Lules of the plains in the east. The term "Lules" or "Juris," as used by the early Spanish chroniclers, did not apply to a certain tribe but signified the nomadic Indians, the *gente desnuda,* of the plains, who lived in the main as hunters, fishers, and collectors of wild fruits.[24]

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[20] There is doubt about a possible rule of the Incas over the Tucumán area. For a complete documentation of the question *see* Boman, E., *op. cit.*, vol. 1, pp. 187–212, and several statements of Garcilasso de la Vega, Montesinos, and others, that the Diaguitas of Tucumán were originally under the dominion of the Incas. The possibility exists that they recovered independence through the downbreak of the Inca power, initiated before the Spanish conquest by the civil war between Atahualpa and Huascar, and further accomplished by Pizarro's invasion.

[21] Sotelo de Narvaez, P., Relación de las provincias de Tucumán, *in* Relaciones geográficas de Indias, Perú, vol. 1, p. 147 (Madrid, 1885): "tienen maneras de vivir como los del Pirú."

[22] *Op. cit.*, vol. 1, chapter on Rapports entre l'ancienne civilisation péruvienne et la culture préhispanique de la région diaguite, pp. 187–212.

[23] *Op cit.*, p. 147: "aunque tienen caciques y es gente que los respetan, son behetrías, que no hay más señores en cada pueblo e valle y son muchos valles y pueblos pequeños."

[24] *Op. cit.*, p. 149: "Los Lules es una gente que no tiene asiento y se sustentan de caza y pesquería." For a full discussion of the meaning of the terms Lules and Juris, *see* Boman, E., *op. cit.*, vol. 1, pp. 41–42.

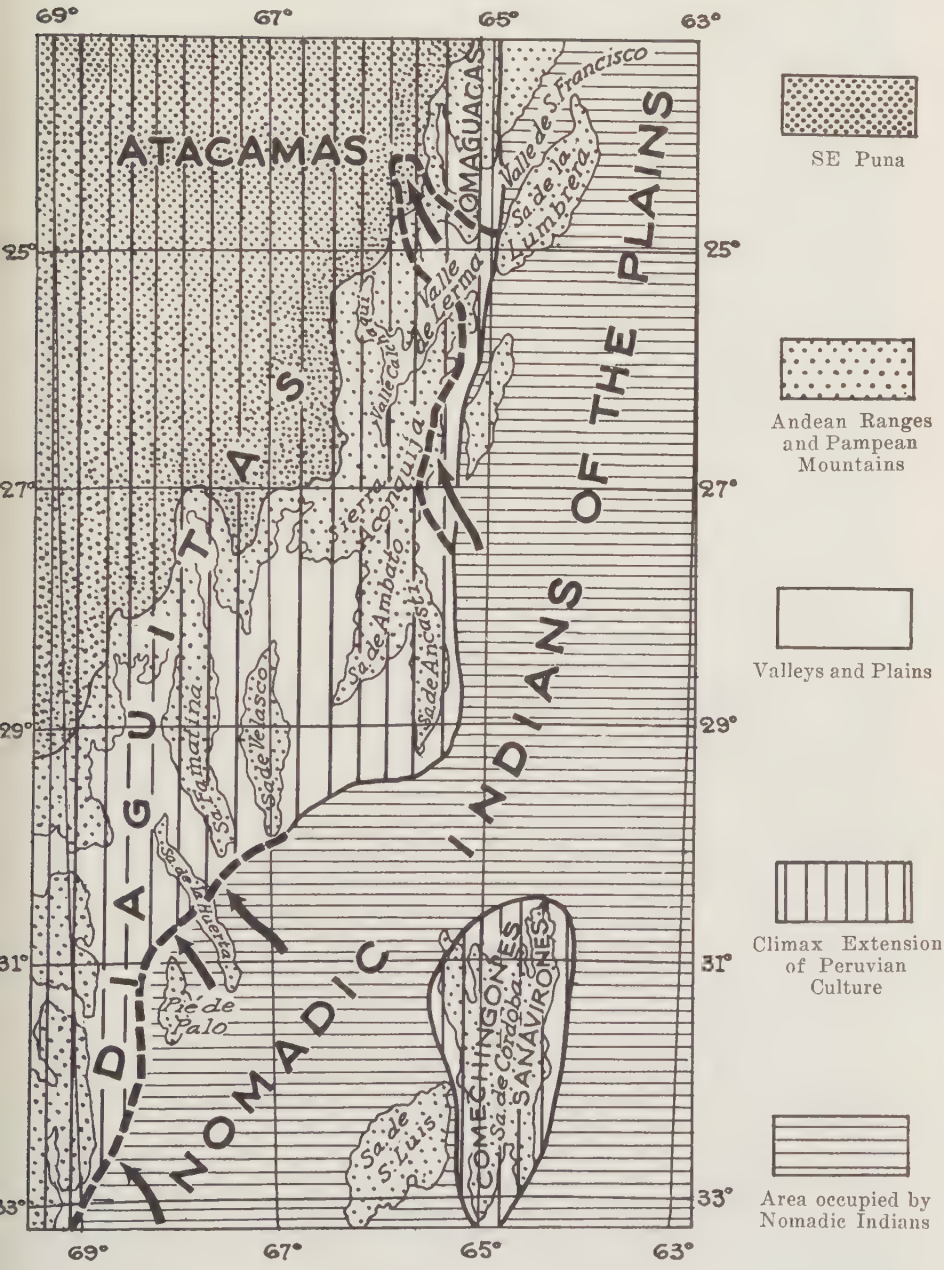

Fig. 2. The morphologic areas of Tucumán and the distribution of pre-Columbian cultures.

PRE-COLUMBIAN SETTLEMENTS

The pre-Columbian settlements of Tucumán had to be adapted to this state of political insecurity as well as to the prevailing economic activity of the population—agriculture. A study of the still existing ruins reveals certain types of settlements which differed considerably in detail; the material of construction, however, was the same throughout Tucumán, namely, *pirca*, thatched with grass. The leading motive for the location of all the settlements was evidently to obtain protection through the natural features of the site (*Schutzlage*). Isolated steep hills, such as spurs at the confluence of two rivers (fig. 3), seem to have been preferred. Where the location of the fields made it necessary to settle down in an unprotected plain, they had a second fortified settlement not far away to which they could move in case of danger.[25] This system was identical with that used by the Collas of the Peruvian highlands.[26]

The rules sketched above controlled the location of all the pre-Columbian settlements of Tucumán; their plans and house types were, however, quite different. In certain settlements round houses prevailed but in a far greater number, rectangular ones. The Comechingones, the linguistically independent aboriginals of the Sierra de Córdoba, who probably formed an advanced and isolated outpost of the Peruvian culture area (fig. 2), were reported to have built their houses partly underground "like cellars" and so large that several families lived together in each house.[27] This statement concerning house-types

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[25] Boman, E., *op cit.*, vol. 1, p. 314, describes the ruins of Tinti located in the plain near Rosario de Lerma, and near by, protected in a *quebrada*, another village which evidently belonged to the same people. Bruch, C., *op. cit.*, pp. 41 and 124, describes similar conditions for Punta Balasto and Fuerte Quemado.

[26] Pedro de Mercado de Petralosa, Relación de la provincia de los Pacajes, *in* Relaciones geográficas de Indias. Perú, vol. 2, p. 62 (Madrid, 1885): "Las fortalezas que tuvieron eran los cerros altos que ternan áspera subida y donde habia algunas fuentes de agua; en los cuales se acugian e cercaban (*sic*) la entrada, y así estaban seguros de sus enemigos.

[27] Relación de la tierra y poblaciones que don Gerónimo Luis de Cabrera ha descubierto, 1572–73, *in* Relaciones geográficas de Indias. Peru, vol. 2, p. 141 (Madrid, 1885): "son los pueblos chicos, quel mayor terná hasta 40 casas y hay muchos de a 30 y a 15 y a 10 y a menos. . . . Tienen los pueblos puestos en redondo y cercados con cardones y otras arboledas espinosas que sirven de fuerza y esto por las guerras que entrellos tienen. Viven en cada casa a cuatro y a cinco indios casados y algunos a más. Son las casas por la mayor parte grandes. . . . Son bajas las casas, é la mitad del altura que tienen está debajo de la tierra y entran á ellas como a sótanos. . . . Son grandes labradores que en ningun cabo hay aguas o tierra bañada que no siembren . . .

Fig. 3. Ruins of the pre-Columbian settlement at Puerta de Tastil in characteristic *Schutzlage* on the spur at the confluence of two streams (from E. Boman).

in the Sierra de Córdoba has not been corroborated as yet by any archaeologic finds in this well-known mountain and is not in harmony with the report of another eye-witness of the conquest of the Córdoba area, who relates that the natives lived in natural caves.[28]

The ancient town of Tastil was evidently of a particular and unique type[29] (fig. 3). Only a few streets cross this settlement, the population of which has been estimated as about 3,000, based on the number of some 800 dwellings. None of the houses had doors, and no indication has been found among the ruins which might explain how the inhabitants entered their houses or passed from one to the other. Nor does any historic source give an answer to this question. A remark which Cieza de León makes on the villages of the Collas comes closest to revealing what the ruins of Tastil apparently imply. "The houses of the villages are built of stone, are roofed with straw, and are placed close together."[30] Since doors are entirely wanting in the ruins of Tastil, there remains only the possibility that the inhabitants of the ancient town passed over the roof in order to get from room to room or from one house into the other, as is the custom of the North American Pueblo Indians.[31]

All ruined settlements show an absolutely irregular plan; the dwellings are scattered about without any apparent rule in their distribution. Among none of the abandoned settlements of Tucumán are there remains of what might be considered palaces, temples, or other major buildings constructed of carefully cut stones, such as characterize many of the ruins of Perú.

The enmity between the different groups of Tucumán, which the early Spaniards reported, cannot have represented a permanent state

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[28] Declaration of Andres de Conteras of Córdoba, Nov. 13, 1589, *in* Gobernación de Tucumán, *op. cit.*, p. 435: "han tenido recuentros los dichos conquistadores y moradores andando en dicha conquista con los naturales buscandolos por las peñas y cerros donde abitan . . . por ser yndios que no tienen pueblos formados sino deuididos de uno en uno en las concavidades de las peñas donde hacen sus moradas . . .

[29] Boman, E., *op. cit.*, vol. 1, pp. 367 ff.

[30] The travels of P. de Cieza de León (1532–1550) contained in the first part of his Chronicle of Perú. Eng. trans., p. 358 (London, 1864).

[31] Ten Kate, H. F. C., Rapport sommaire sur une excursion archéologique dans les provinces de Tucumán et de Salta, Revista del Museo de La Plata, vol. 5, pp. 329 ff. (La Plata, 1894). The author called attention for the first time to the existing analogies between the civilization of the Calchaquí Indians of Tucumán and the Pueblo Indians of the American Southwest. I. B. Ambrosetti goes so far as to establish a common descent for the Calchaquí and the Pueblo Indians. *See* Rastros etnográficos comunes en Calchaquí y Mexico, Anales de la Sociedad Científica Argentina, vol. 51, pp. 5 ff. (Buenos Aires, 1911); La civilisation calchaquí, 12 Congrès intern. des Americanistes, Paris, 1900, pp. 293 ff. (Paris, 1902); and I Calchaquí Boletín della Societá geográfica Italiana (Rome, 1903).

of warfare. On the contrary, there seems to have been intensive communication between the different settlements, for this view alone would justify the construction of such remarkable roads as have been preserved in some sections.[32]

PRE-COLUMBIAN ECONOMIC LIFE

The chief means of sustenance of the Indians of Tucumán, so far as they belonged to the Peruvian *Kulturkreis*, was agriculture, which was as highly developed among them as anywhere else in the Inca empire. They stored water in *represas*, artificial reservoirs, the remains of which are still in existence.[33] They excavated *acequias*—irrigation ditches—and watered their fields carefully.[34] Their system of terracing the fields was identical to that employed by the Peruvian highland Indians and the pireas which they constructed for this purpose are still conspicuous features in many parts of the northwestern Argentine landscape. The location of their fields depended mainly on natural conditions, especially on water supply for irrigation. In one case, at least, the site of their fields was in a valley, accessible only with great difficulty and far from the next settlement. This was selected by the natives in order that their crops might be protected from hostile invaders.[35] It was thus in pre-Columbian times that the native population of Tucumán brought agriculture to its climax; their abandoned, terraced fields lie in areas where the present-day population carries on merely primitive stock raising.[36]

Agriculture based on rainfall was possible only in the eastern part of old Tucumán, adjoining the land of the nomadic Indians. Sotelo

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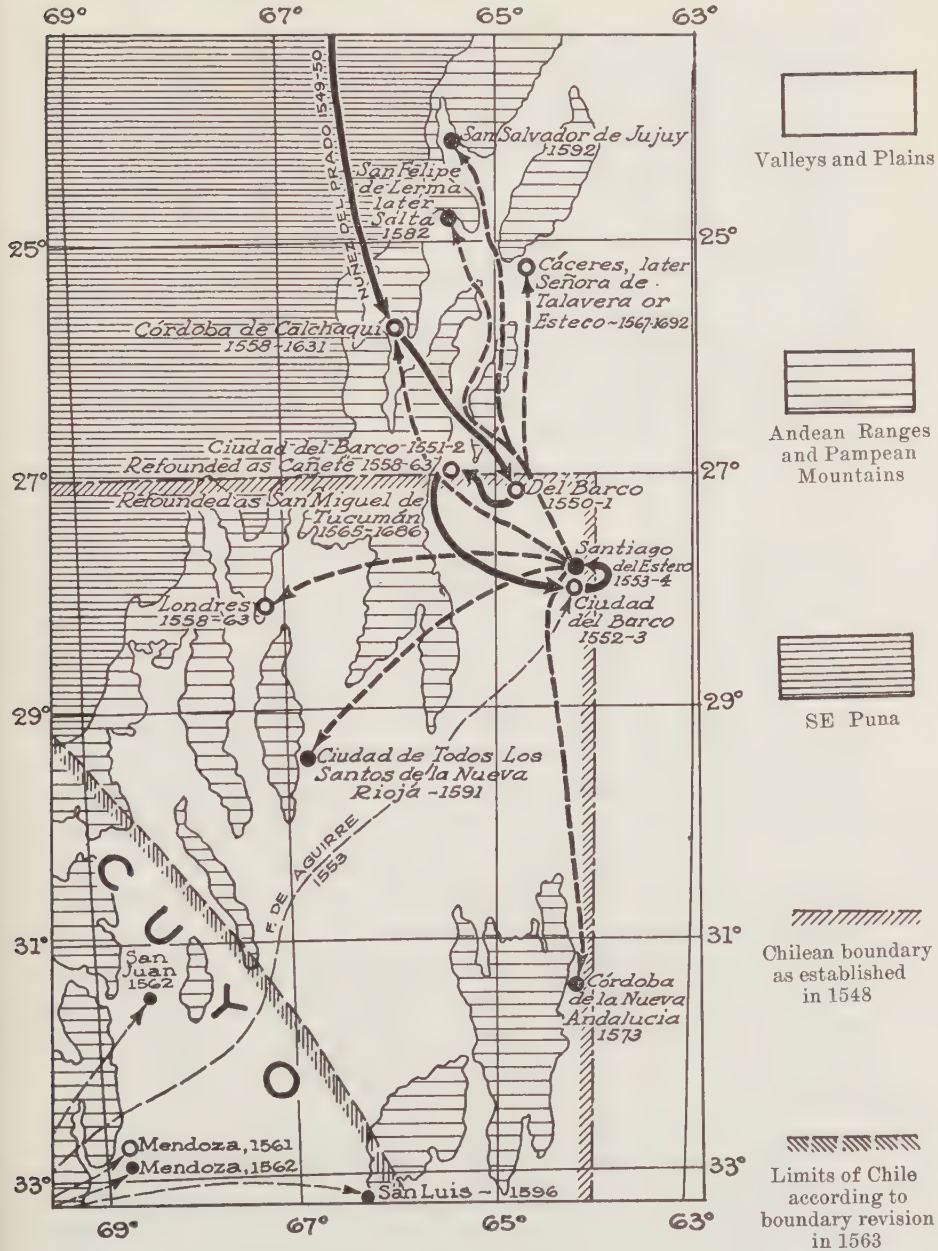
[32] Boman, E., *op. cit.*, vol. 1, pp. 345–348, describes the pre-Hispanic road from Morohuasi to Incahuasi and Payogasta. A second well built road runs from Morohuasi to Tastil and from there into the Valley of Calahaquí.

[33] Bruch, Carlos, *op. cit.*, p. 191, describes the ruins of such an artificial reservoir near the ruins of Tuscamayo.

[34] Sotello de Narvaez, *op. cit.*, p. 148, describes the agriculture of the Diaguitas in the Calchaquí valley: "siembran con acequias de regadio todo lo dicho."

[35] Debenedetti, Salvador, Las ruinas prehistóricas de El Alfarcito, Boletín de la Academia Nacional de Ciencias in Córdoba, Argentina, vol. 23, pp. 287–318 (1918).

[36] As an instance may be cited the vivid picture which Lafone Quevedo gives of the many remains of dwellings and andenes of the aboriginals west of the Sierra de Ambato, which prove that a dense agricultural population once lived along the stony desert (*áridos pedregales*) slopes of the mountain. Quevedo, Lafone, Las ruinas de Lajanco y Tuscamayo, Revista del Museo de La Plata, vol. 10, pp. 257 ff. (1902).



Sites of unsuccessful attempts to found towns.

Towns successfully founded.

Route of Nuñez del Prado.

Colonization from Santiago del Estero.

Colonization from Santiago de Chile.

FIG. 4. SPANISH COLONIZATION OF TUCUMAN.

Narvaez[37] reports that the Tonocotés, who lived near the colonial town of Talavera (fig. 4), situated where the Rio Juramento leaves the mountains and enters the plains, relied entirely on rainfall. The crops were the same as in the rest of Perú—potatoes, quinoa, corn, pumpkins—and supplied the important elements of their diet. Live stock was restricted to the llama,[38] whose range extended south as far as the Sierra de Córdoba.[39]

In addition to agriculture and stock raising, the aboriginal inhabitants of old Tucumán were hunters, and collectors of wild fruits. The guanaco, deer, vizcacha, and armadillo were hunted; and the monte, penetrating into the valleys, was rich in such trees as *algarrobo* and *chañar,* which bear nutritious fruits in great quantities.[40]

CULTURAL DECAY AT THE END OF THE PRE-COLUMBIAN PERIOD

Considering the great number of pre-Columbian ruins of Tucumán, some of which prove the existence of important urban settlements during that period, it seems strange that none of the early Spaniards give an adequate description of the highly developed cultural landscapes which they must have encountered. Important urban settlements and areas once intensively cultivated are not even mentioned.[41] It seems reasonable to believe that decay overcame the area before their arrival, and this idea is strengthened by certain statements of early Spaniards.

We know very little as to the condition in which Almagro and his companions, the first Spaniards to enter Tucumán (1536), found the area. Yet Oviedo y Valdés[42] reports that the country from Jujuy in the north to Chicoana in the south had been invaded and

[37] Sotelo de Narvaez, *op. cit.*, p. 149: "Es gente labradora . . . siembran de temporal. Vistense por la orden que los del Pirú, de algodon y lana . . ."

[38] *Ibid.*, p. 144: "ganado que tenian de la tierra como lo desta del Pirú."

[39] Cabrera, G. L., de, Relación en suma de la tierra y poblaciones de las provincias de los Juries. 1572–73, *in* Relaciónes geográficas de Indias. Perú, vol. 2, p. 140 (Madrid, 1885): "crian mucho ganado de la tierra."

[40] Sotelo de Narvaez, *op. cit.*, p. 147, says of the Diaguitas: "Tienen mucha caza de venados, guanacos, liebres y la demás que en la tierra llana; tienen muchos algarrobales de importancia, y entre ellos chañarales."

[41] E.g., the agricultural area west of the Sierra de Ambato described by Lafone Quevedo, *op. cit.*

[42] Gonzalo Fernandez Oviedo y Valdés (–1557), Historia general y natural de las Indias, vol. 4, libr. XLVII, pp. 263–265 (Madrid, 1851–55).

destroyed by the Juries, who were nomadic Indians (*indios alárabes*). This statement of Almagro's is supported by what we know about the valley of Salta or Lerma through Boman,[43] who describes the many remains of a more highly civilized native population with a culture based on agriculture. Yet when the town of San Felipe de Lerma was founded in 1582, the site was selected not because a numerous agricultural population was concentrated there, but because "between Siancas and the Rio de los Sauces there were acequias from the time of the Incas."[44] The report of Sotelo de Narvaez, in the year 1583, describes the valley of Lerma as "good and fertile," yet makes no allusion to a civilized agricultural population, but adds that the valley is uninhabited (*no tiene indios*). By this he meant that it lacked such Indians as would make useful subjects to the Spaniards, since he records further that some 1,500 nomadic Indians lived there.[45]

These statements would appear to support the assumption that an important cultural change had taken place in parts at least of the valleys of Tucumán before the coming of the Spaniards. We cannot, however, determine exactly how extensive an area was affected by this cultural succession of the pre-Columbian period, since the statement of Almagro[46] is rather vague. Figure 2 gives only a most conservative estimate, based on actual knowledge, of the extent of the area in which the original population of Indians of Peruvian culture had been replaced by nomadic Indians from the plains. The assumption has elsewhere been made that Tucumán in its totality might have been invaded and devastated by plains Indians before the arrival of the Spaniards.[47] There is certainly no doubt that a cultural succession and a consequent change in the aspect of the landscape had been initiated before the Spaniards; that the skilfully made andenes and fields of the Diaguitas, together with their unprotected and unfortified settlements had been destroyed.

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[43] Boman, E., *op. cit.*, vol. 1, pp. 247–316.

[44] See quotation *in* R. D. Carbia, Historia de la civilización Argentina, p. 427 (Buenos Aires, 1917).

[45] Sotelo de Narvaez, *op. cit.*, p. 150: "este valle de Salta es muy bueno y fértil . . . corre 30 leguas, poco más ó menos, tiene dos leguas de ancho, menos y más, es de temple más fresco que lo de Santiago tiene muchas aguas de rios . . . Es muy aparejada para criar ganados y para cosechas de buena comida . . . no tiene indios, porque hasta 1500 que puede tener es gente de poco asiento y los más Lules, aunque siembran y tienen ganados."

[46] Oviedo y Valdés, *op. cit.*

[47] Ten Kate, H. F. C., Anthropologie des anciens habitants de la région calchaquie, Anales del Museo de La Plata, Sección antropología, vol. 1, p. 5 (La Plata, 1894).

An inquiry which the Procurador of the Cabildo of Santiago del Estero made in 1585 among those burghers of the town who were eye-witnesses of the conquest, gives a most illuminating description of the situation:[48]

> The Lules who are robbers and warriors drove them [the aboriginals of Peruvian culture] together and besieged them in their fortified places. They took away their farms in which they cultivated corn, quinoa and pumpkins, their main food supply, while said Lules, on the other hand, lived only on what they could get by stealing, robbing and killing. They had no agriculture and were like the Arabs, eating all they could get from the natives. If the conquistadores had not interfered, they would have destroyed and finished with said natives. The Spaniards did great service to God our Lord and his Majesty in rendering help to said natives and defending them from being killed.

It therefore seems logical to conclude that the fact that most of the native settlements of Tucumán were abandoned by their inhabitants during the first part of the sixteenth century was not at all due to the Spanish *conquista*, as had been the case in the rest of Perú. If we believe Lozano,[49] a great emigration of the people of Tucumán took place into the Gran Chaco shortly before the Spaniards entered the area, a great drought with consequent famine being its cause. The statement seems credible since the agricultural population of Tucumán, to judge from the archaeological remains, must have been so numerous that only an exhaustive utilization of all the available surface water for irrigation could produce crops sufficient for their maintenance. One or several years of abnormally low rainfall, such as occur in arid regions, might easily have produced scarcity of crops, famine, and even a cultural crisis, since the warlike Indians of the plains could take advantage of the situation and invade the country.

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[48] Información levantada por el procurador del Cabildo de Santiago del Estero entre los vecinos. Santiago del Estero, 1585, *in* Gobernación del Tucumán, *op. cit.*, p. 116 (Madrid, 1918): "Los Lules que son una gente salteadora e belicosa los tenian acorralados e metidos en pucaranes y fuertes quitandolas las chacaras que tenian de mays, quiuna e çapallo que es el principal sustento que tenian porque los dichos lules no bibian de otra cosa sino de robar hurtar e matar e no sembraban comiendoles quanto tenian que son figurados como los alaraues e si los dichos conquistadores los dexaron los obieron destruido acabado y asolado los dichos naturales que solamente por esto hicieron gran servicio a dios nuestro señor y a su magestad . . . ayudando a los dichos naturales y defendiendo que no los matasen."

[49] Lozano, P., Historia de la conquista del Paraguay, Rio de la Plata y Tucumán, 1745, vol. 4, p. 25 (Buenos Aires, 1873–1875).

THE ALTERATION OF TUCUMAN IN THE COLONIAL PERIOD

Early explorations.—The first Spaniards to cross parts of Tucumán were Almagro and his companions on their famous march to Chile, in 1536. The first expedition, which started with the express purpose of conquering Tucumán itself, was that of Diego de Rojas (1543). The reports of this *entrada* are not very illuminating for the student of the historic geography of the area. Most of the available accounts are obscure and confusing.[50] The expedition was under experienced direction, Rojas having participated in the conquest of México and in the civil wars of Perú, and the outfit was excellent.[51] It was not, however, the fame of Tucumán as a desirable country which made the Spaniards prepare for its conquest. Perú had an excess of enterprising Spaniards who found no field for their activities. It was only to prevent these people from starting further trouble that the Governor, Vaca de Castro, organized Rojas' so-called[52] "entrada al Rio de la Plata." From this viewpoint the expedition was certainly a success, since few of the proud force found their way back to Perú (1546), but as a colonizing enterprise, the first entrada into Tucumán was an absolute failure. The Spaniards could do little else but defend themselves against the natives and the only settlement which they seem to have founded had a brief existence.[53] No further

[50] Pedro Gutiérrez de Santa Clara, Historia de las guerras civiles del Perú (1544–1548), *in* Colección de libros y documentos referentes a la historia de América, vol. 4, cap. 18–22 (Madrid, 1905); *also,* Cieza de León, Guerra de Chupas, cap. 94.

[51] *Ibid.,* p. 152: "Los que entraron fueron hasta doscientos y cincuenta hombres muy valientes y animosos, los cuales fueron bien aderesçadas las personas y apercebidos de muchas armas, cauallos y gran servicio de negros, negras, yndios, y muchos yndios amigos."

[52] *Ibid.,* pp. 150–151: "porque estando por aca occiosos no se causasse entre ellos algunos bullicios y escandalos con algunos levantamientos como los passados, de donde auian resultado muchas muertes, robos y daños con ynnumerables males y extorssiones . . . por euitar estas cosas y otros muchos ynconvenientes que se podrian recrescer entre los sediciosos y ambiciosos, embio [governor Vaca de Castro] a buscar tierras nuevas a ciertos capitanes, entre los quales fue al Rio de la Plata, por tierra, el capitan Diego de Rojas, con titulo de gouernador de aquellas tierras en nombre de Su Magestad, que fue en el año de 1542."

[53] Only Gutiérrez de Santa Clara refers to the foundation of Medellin in Tucumán, *op. cit.,* vol. 3, p. 163: "F. de Mendoza . . . queria lleuar la mitad de la gente que auia y que la otra mitad se quedassen en aquel pueblo y que . . . hiziessen muchas casas de habitacion, aunque fuesse de paliçada; y assi hordeno una buena poblaçión, la que llamaron Medellin." The author does not give the site of the town nor is its foundation corroborated by any other document.

alterations of the cultural landscape resulted, so far as we know, as a consequence of this first expedition.

Early Spanish colonization.—Spanish cultural influence on the Tucumán area really began with the expedition of Nuñez del Prado[54] (1549–1550). The reason for this second enterprise was the same as in the case of Diego de Rojas,[55] and similarly it proved to be only slightly effective during the first decades, since nature as well as the warlike native population made the conquest extremely difficult.[56] The equipment of the expedition was insufficient, prices for armaments being at that time almost prohibitive in Perú.[57] In addition to these handicaps were others of an administrative nature. The territory accorded to Pedro de Valdivia as *gobernación de Chile* (April 18, 1548) had been limited by 27° S in the north and 41° S in the south, the extension toward the interior having been arbitrarily fixed at one hundred leguas.[58] The area of Tucumán, which Prado was authorized to colonize independently, came thus to lie largely within the

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[54] Provisión de Juan Nuñez del Prado, 19 de Junio de 1549, Gobernación del Tucumán, *op. cit.*, pp. 28–30: "don carlos por la diuina clemencia rrei de alemania . . . vos cometamos y mandamos que vais . . . a la dicha provincia de tucuman y en la parte y sitio que os pareciere mas convieniente para poblar pobleis un pueblo y desde el procureis de traer en paz a nuestra obidiencia y a que oyan . . . nuestra sancta fee catholica todos los caciques principales e yndios de las dichas provincias . . . y para que mejor y con mas rreputacion podais facer y ejectuar to lo sobre dicho vos criamos e fazemos capitan e justicia mayor en el dicho pueblo que asi poblaredes. . . .

[55] Statement made by Captain Juan Rodriguez Xuarez of Santiago del Estero, 1585, *in* Gobernación del Tucumán, *op. cit.*, p. 171: "quedando mucha gente sin suerte dio poderes de capitan general al dicho juan nuñez de prado para que viniese a la poblazion y conquista de esta governacion de tucuman y en ella diese de comer a los que auian quedado sin suerte en el perú."

[56] Información levantada por el procurador de Santiago del Estero entre los vecinos, 1585, *in* Gobernación del Tucumán, *op. cit.*, pp. 114–115: "que conste por extenso los trauajos que pasaron los que la (tierra de Tucumán) ganaron allanaron y conquistaron comiendo cigarras y langostas yeruas rraizes cardones pieles de animales y otras cosas silvestres muriendo de hambre y sed bistiendo de cueros de venados crudos y otras rramas e yeruas padeciendo mucho cansancio derramando mucha sangre a costa de vidas de muchos conquistadores y soldados que viuieron debajo del gouierno y mando del capital juan nuñez de prado . . . teniendo sienpre . . . muchas guerras de los naturales batallas recuentros asaltos y otras guacabaras . . . saliendo siempre vecedores aunque heridos y muertos algunos españoles. . . .

[57] Statement of Captain Miguel de Ardiles of Santiago del Estero, 1585, *in* Gobernación del Tucumán, *op. cit.*, p. 144: "este testigo saue que las armas e caballos valian a quinientos e mill pesos los cauallos e yeguas e las armas muy caras y a excesibos precios e por esta rrazon los españoles no entraron en esta tierra con las armas e pertrechos que se requeria."

[58] Provision que dio el de la Gasca a Baldivia para la governacion de Chile, 18 de Abril de 1548 . . . "por la presente os doy y asyno por gobernacion y conquista desde copiapo que esta en veynte e siete grados de altura de la linea equinocial a la parte del sur hasta quarenta y vno de la dicha parte procediendo norte sur derecho por meridiano y de ancho entrando de la mar a la tierra hueste este cien leguas y os creo y constituyo en la dicha gobernacion . . . ." Gobernación del Tucumán, *op. cit.*, p. 22.

territory of Chile (fig. 4). This fact contributed in great measure to the instability of the early Spanish settlements in the area.

The Spaniards under Nuñez del Prado founded their first town on the plains which border the mountains of Tucumán in the east. No available report gives a reason for the selection of this site in the land of the nomadic Indians, and only the assumption that they found agriculture in the interior valleys in decay or destroyed could explain it. Ciudad del Barco, the newly founded settlement, had a short life. It had hardly been founded when it was claimed by the Spaniards from Chile. To escape from Chilean jurisdiction, Nuñez transferred his town in 1551 to the valley of Calchaquí (fig. 4). But the new site, chosen to avoid administrative difficulties, proved to be undesirable also, and El Barco the Second was given up in 1552, apparently because of the insufficient number of natives in the valley. They had scarcely founded it for the third time (1552) in the eastern plains on the banks of the Rio Dulce when an emissary from Chile arrived and transferred it to a fourth site (1553–1554), a short distance to the north,[59] where it was less exposed to inundations. With this new and finally definite location, the name of the settlement was changed to Santiago del Estero, and through it the Spaniards obtained an actual stronghold in Tucumán. For several years it remained the only Spanish settlement in the area, but in the course of time it became the center from which Spanish cultural influence spread out and penetrated throughout Tucumán.

SANTIAGO DEL ESTERO, THE FIRST SPANISH SETTLEMENT IN TUCUMAN

Several years had to pass before the new town of Santiago del Estero acquired sufficient importance to fulfil its function as a center of colonization. The site of the settlement made for the isolation of the inhabitants from other centers of Spanish culture in South America,[60] while the nomadic character of the Indians among whom

[59] Statement made by Antonio Alvarez of Santiago del Estero, 1585, *in* Gobernación del Tucumán, *op. cit.*, p. 227: "juan nuñez de prado estando poblado en el valle de calchaqui despobló alli por parecerle que auia poca gente en el y pobló desspues esta ciudad cerca de donde agora está despues la pasó de alli al sitio donde agora está poblada el governador francisco de aguirre y le puso el nombre que agora tiene . . ."

[60] Carta a S. M. de la ciudad de Santiago del Estero, 11 de Diciembre de 1575, *in* Gobernación del Tucumán, *op. cit.*, p. 86: "en este rincon tan apartados vivimos. En el qual no solo el estar lexos pero la pobresa y miseria grande de nuestro vivir es tanta que por qualquier dellas dos podemos crer estar fuera de toda memoria. . . ."

they had settled retarded considerably development of the agriculture necessary to maintain the population. In fact, the community fared so badly that they were obliged to dress themselves in the furs of wild animals and to do their own sowing, since the Indians refused to work for them.[61]

For the first two or three years the influence of the Spaniards upon the landscape was negligible. The two Dominican monks, who accompanied Prado's expedition in order to spread the gospel among the natives, had turned back to Perú when they realized the difficulties which their task would involve.[62] The colonists did, indeed, have their own settlement, but they lived the life of the Indians, dressing as the natives did, and raising their crops.[61]

Two or three years later, a group of Spaniards, returning to Santiago del Estero from a journey to Chile, brought back with them a priest; but they also brought seeds of cultivated plants such as wheat, barley, cotton, etc.[63] The importation of these plants meant a great improvement in the living conditions of the people of Santiago. Certain plants formed a new basis for their diet while cotton cloth became not only the essential element in their clothing and that of the Indians,[64] but in the early colonial period took the place of currency in Tucumán.[65]

Thirty years later agriculture was well developed around the town, and the Indians, of whom there were about 12,000 who paid taxes and who were distributed among forty-eight Spaniards,[66] grew crops from

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[61] Statement made by Francisco de Carabajal of Santiago del Estero, 1585, *in* Gobernación del Tucumán, *op. cit.*, p. 205: "bestidos de cueros de animales de pellejos de perros hacian botas y comian raices e yeruas y sembraban lo que comian por sus manos por no seruir los yndios. . . ."

[62] Statement made by Miguel de Ardiles of Santiago del Estero, 1585, *in* Gobernación del Tucumán, *op. cit.*, p. 144: "este testigo vido que el dicho capitan juan nuñez de prado quando entró en estas prouincias entraron con él los dos religiosos de la orden del señor santo domingo los quales por uer los traubajos e necesidades de la tierra e poco fruto della la dejaron e se fueron al peru e los españoles quedaron sin sacerdotes . . . y asi estuvieron tres años poco mas o menos. . . ."

[63] Información levantada por el procurador del cabildo de Santiago del Estero, 1585, *op. cit.*, p. 116: "traxeron algunas semillas de trigo, cevada y otras cosas de castilla e algodon." Page 145: "se quieto la gente de españoles e se empesaron a dar a sembrar las dichas semillas de frutas y algodon con que se vistieron."

[64] *Ibid.*, p. 145: "el dicho algodon a sido y es gran remedio para los españoles e naturales e su sustento por que con el se visten e antes carecian de todo ello en esta tierra."

[65] *Ibid.*, p. 129: ". . . por no tener oro ni plata sino solo bestidos de yndios que es mantas camisetas calcetas y alpargatas y lienço de algodon que es la moneda que corre en esta governación. . . ."

[66] Sotelo de Narvaez, *op. cit.*, p. 143: "tiene esta ciudad cuarenta y ocho vecinos encomenderos de indios, los cuales se sirven de doce mill indios, poco mas o menos, y les dan tasa."

the imported plants. Extensive vineyards provided them with grapes and wine; peaches, figs, melons, quinces, apples, pomegranates, grapefruit, and oranges were abundant crops. Wheat, corn, barley, garbanzos, garlic, onions, and many vegetables were also grown. The fields lay partly on land which the river inundated, while other fields were irrigated by an acequia, over a league long, made by the Spaniards. As a whole the land around Santiago was considered "abundante de comidas."[67]

In addition to agriculture, stock raising early became important. Livestock was imported from Perú[68] and increased rapidly; by 1583 the people of Santiago had a large number of horses, cattle, mules, sheep, goats, and pigs.[69] Weaving became the principal handicraft and woolen and cotton goods were produced in such quantities that blankets and cloth were the first exported articles to find a good market in the highlands of Perú. The colonists had thus a source of income which made it possible for them to pay for the import of necessary European articles.[70]

First Attempt to Colonize from Santiago del Estero

With the first stronghold of Spanish culture well established in Santiago del Estero, a desire to bring the whole of Tucumán under Spanish control naturally developed. The first premature attempt was made as early as 1558 when Governor Perez de Zurita founded three new towns (fig. 4): Londres in the valley of Quinivil at the foot of the Sierras de Belén, Cañete in the valley of Guazán, and Córdoba in the valley Calchaquí.[71] The new settlements existed for a short time only. Conflicts between the Spaniards themselves, arising out of the question of cognizance of the Chilean governor over the new colonies in Tucumán, weakened their force.[72] The Indians of the

[67] *Ibid.*, pp. 144–145.

[68] Statement made by M. de Ardiles, 1585, *op. cit.*, p. 145: "de las provincias del piru trajeron vacas e ovejas e otros ganados y en esta sazon entro del Reyno de chile juan perez de curita." This was in 1558.

[69] S. de Narvaez, *op. cit.*, p. 145.

[70] *Ibid.*, pp. 144–145.

[71] Información levantada por el procurador del Cabildo de Santiago, *op. cit.*, 117: "entro juan perez de corita . . . e poblo tres ciudades en el valle de quinivil la ciudad de londres y en calchaqui la ciudad de cordoba y en tucuman la ciudad de cañete para las quales llevaron los vezinos desta ciudad muchos cavallos yeguas y ganados de ovejas y cabras. . . ."

[72] A letter of the cabildo of Santiago del Estero to the king of Spain, December 18, 1586, *in* Gobernación del Tucumán, *op. cit.*, pp. 253–260, gives an impressive synthesis of the administrative difficulties since the beginning of the colonization and comes to the following conclusion: "los mesmos capitanes

interior valleys took advantage of the situation in a general uprising, during which the three newly founded settlements were destroyed and abandoned by the Spaniards.[73] The town of Nieva, founded in 1561 in Jujuy, shared their fate and Santiago del Estero was once more the only Spanish stronghold in Tucumán. Even this town was seriously endangered by the attacks of the Indians.[74]

In 1563 the difficulties emanating from the question of cognizance over Tucumán were finally solved. The "gobernación de tucuman juries y diaguitas" was detached from Chile and came under the audiencia de Charcas.[75] Only the so-called area of Cuyo in the extreme south remained with Chile almost throughout the colonial period in spite of its location on the eastern slope of the Andes (fig. 4). Not until 1776 was Cuyo detached from Chile to form part of the newly created viceroyalty of the La Plata. During the larger part of the colonial period, Spanish colonization of the two areas therefore proceeded independently. Santiago de Chile became the starting point for the colonization of the Cuyo area while Tucumán had its own center of Spanish culture in the town of Santiago del Estero, which eventually became strong enough to make its cultural influence felt also in the interior valleys.

Yet, even with the disturbing influence of Chile eliminated, colonization of Tucumán proceeded but slowly. Sporadically appearing Spanish settlements, which vanished after a short existence, represented in the main the visible effect of Spanish influence on the landscape. Nieva, founded in 1561 in Jujuy, and San Clemente de la

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y governadores se an unos a otros consumidos y la guerra desasosiego y travajos la an padescido estos vuestros leales vasallos . . . por aver sido tantos los capitanes y governadores y tan presto sacados de su govierno a sido vuestra magestad deservido y esta governacion muy vexada."

[73] Statement made by M. Ardiles, *op. cit.*, p. 146: "por la mudança de capitanes que uvo . . . se rreuellaron las provincias de los diaguitas e tucuman y echaron los españoles de la tierra a pura fuerça de guerra y se despoblaron las dichas tres ciudades (Londres, Cañete and Córdoba de Calchaquí) que se abian poblado . . . por . . . juan perez de çurita con el socorro fabor e ayuda que para ello dio esta dicha ciudad de santiago del estero e los yndios mataron muchos españoles hombres mujeres e niños en la ciudad de cordoua en el dicho valle de calchaqui. . . ."

[74] Información levantada por el procurador del cabildo de Santiago del Estero, *op. cit.*, p. 117: "quedo sola esta ciudad en pie aunque en gran riesgo por causa de la poca gente que auia quedado en esta tierra. . . ."

Carta de la Audiencia de Charcas a Su Majestad, etc., Oct. 30, 1564, *in* Audiencia de Charcas. Documentos del Archivo de Indias, vol. 1, pp. 133–144 (Madrid, 1913).

[75] Real provision, 29 de Agosto de 1563, *publ. in* Correspondencia de la Audiencia de Charcas. Page 588 ". . . avemos acordado de . . . ordenar asi apartar la dicha governación de tucuman juries y diaguitas de la dicha gobernación de chile e incluirla en el distrito de la dicha audiencia de los charcas. . . ."

Nueva Sevilla, founded first in the valley Calchaquí in 1576, and reestablished in 1577, after its destruction by the Indians, in the valley of Salta, were types of such settlements, which proved failures from their very foundation.

Successful Colonization at the Border of Mountains and Plains

The first successful foundation, which proved that Santiago del Estero had indeed acquired sufficient vigor to become the starting point for further colonization ("tenia valor e pujança para poblar nuevas ciudades"),[76] was San Miguel de Tucumán (1565?). The new town was founded on the site where Nuñez del Prado had once built his second Ciudad del Barco.[77] It was long dependent on succor from Santiago del Estero,[78] but even so, its existence was frequently endangered by hostile Indians in the neighborhood. At one time the Indians succeeded in burning the whole settlement so that the colonists were on the point of abandoning it.[79] These difficulties of the early period were eventually overcome. The poverty of the colonists was probably not so great as they themselves painted it in order to get new *mercedes* from the crown[80] or cheaper rates for masses and burials.[81] By 1583, the people of San Miguel de Tucumán held in service three thousand Indians—Diaguitas, Tonocotes, and Lules. Their land was classed as "muy abundante de comidas"; agriculture was pursued on irrigated and inundated land (bañados) as well as relying simply on rainfall; they had many orchards with Castilian fruit trees; and their live stock was numerous. The trees of the luxuriant mountain forests provided them with excellent lumber

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[76] Información levantada por el procurador del Cabildo de Santiago del Estero, *op. cit.*, p. 118.

[77] *Ibid.*, p. 142: "juan nuñez de prado poblo en el valle de tucuman una ciudad que llamaron la ciudad del Barco do esta agora poblada la ciudad de san miguel de tucuman. . . ."

[78] *Ibid.*, p. 118: "la ciudad de san miguel de tucuman que esta veynte e cinco leguas desta ciudad hazia la sierra de tucuman la cual se sustento con el socorro y amparo desta ciudad hasta ponella en el punto y estado que esta el dia de oy. . . ."

[79] Letter of the city of San Miguel de Tucumán to the king of Spain, July 6, 1588, *in* Gobernación del Tucumán, *op. cit.*, pp. 340–341: "an acudido muchas vezes estos yndios a darnos guerra y a ynquietarnos en nuestras casas hasta quemarnos la ciudad una noche que estubo en terminos de despoblarse."

[80] Letter of the city of San Miguel de Tucumán to the king of Spain describing the many hardships of the colonists, 1589, *in* Gobernación del Tucumán, *op. cit.*, 346–347.

[81] Poderes que las ciudades de . . . San Miguel de Tucumán . . . otorgan a Manuel Rodriguez Guerrero, 1585–1588, *in* Gobernación del Tucumán, *op. cit.*, p. 104.

which they shipped to the other Spanish settlements.[82] The town persisted on this original site until 1686 when it was transferred to the place where the modern city of Tucumán now stands.[83]

The next successful settlement which arose in the plains at the foot of the mountains was the Ciudad de Cáceres (1567), afterward called Nuestra Señora de Talavera or Talavera de Madrid, and later Esteco (fig. 4). Similarly situated on the plain, with the Sierra de Córdoba in the background, was founded, in 1573, Córdoba de la Nueva Andalucía. These settlements were the direct outgrowth of the increasing importance of Santiago del Estero. They proved that this old colony had actually acquired at that time sufficient "valor e pujança" to build up new towns. Talavera as well as Córdoba received no help from the Spanish crown. Not only were the colonists Spaniards from Santiago, but they got all they needed from the old colony, arms, soldiers, wagons, cattle, horses, provisions, and Indians for service. The importance which live stock had acquired in the border land between the mountains and the plains is evidenced by the fact that the expedition which founded Córdoba took along a thousand horses.[84]

By 1583 Córdoba and Talavera were well established. Their live stock was numerous and agriculture had developed along the same lines as at Santiago del Estero.[85] Tucumán had thus four Spanish towns: Santiago del Estero, San Miguel de Tucumán, Nuestra Señora de Talavera, and Córdoba de la Nueva Andalucía. San Felipe de Lerma in the valley of Salta was simply a military fort without colonists.[86] The four towns were located in the plains at the eastern border of the mountains, surrounded on all sides by an unsubdued aboriginal population. More than thirty years had passed since Nuñez del Prado started the colonization of Tucumán, yet not a single Spanish colony had succeeded in the interior valleys of the area. Spanish cultural influence, however, had preceded the Spanish settlements. The Indians of the valley of Calchaquí, who had effectively defended their independence, had at that time large numbers of imported cattle (*ganados de Castilla*), and cultivated wheat, barley, and many imported vegetables.[87]

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[82] Sotelo de Narvaez, *in* Relac. geogr., *op. cit.*, pp. 148–149.

[83] Diego de la Vega, Guia de Forsteros del Vireynato de Buenos Ayres para el año 1803, Apéndice, p. 537 (Buenos Aires, Junta de Historia y Numismática Americana, 1908).

[84] Gobernación del Tucumán, *op. cit.*, p. 118; *ibid.*, p. 137.

[85] Sotelo de Narvaez, *op. cit.*, pp. 149–152.

[86] *Ibid.*, p. 150.

[87] *Ibid.*, pp. 147–148.

COLONIZATION OF THE INTERIOR VALLEYS

At the end of the sixteenth century the successful colonization of the interior valleys began. The foundation of San Felipe de Lerma in the valley of Salta (1582), of Todos los Santos de la Nueva Rioja (1591), and of San Salvador de Jujuy (1591) not only broke the resistance of the natives but also made communication safe with the highland of Perú. Through-going traffic from the La Plata to Chile and Perú early acquired a certain importance.[88] Portuguese merchants from Brazil took advantage of the high prices of manufactured articles imported via Panamá, and appeared with their goods in Santiago del Estero as early as 1586.[89]

Aside from the favorable effect which the developing traffic through Tucumán had on the economic life of the area, one of the most serious consequences was the decrease of the native population through emigration. Travelers, merchants, and soldiers took with them Indians from the exclusively agricultural province of Tucumán, and once arrived in Perú, which was at that time economically the most active and prosperous part of South America, the Indians would not return to their native country, even though they might have left a family there.[90] In six years, Santiago del Estero, including the surrounding area, lost in this way over two thousand Indians of the eight thousand which it had originally.[91] When the town of Nueva Rioja was founded (1591) there lived in its neighborhood, i.e., at distances of less than eight leagues, some three thousand Indians. The *encomienda* reserved for the governor contained eighteen pueblos

[88] Letter from the cabildo of Santiago del Estero to the king of Spain, Dec. 18, 1586, *in* Gobernación del Tucumán, *op. cit.*, p. 259: "esta ciudad esta en el comerçio y camyno del rio de La Plata y provincias del Pirú y trato y camyno de Chyle y el Brasil y de las unas a las otras provinçias se va entrando y saliendo y ai muchos pasajeros y tratantes. . . ."

[89] *Ibid.*, p. 259: "ay en esta ciudad mercaderes portugueses que an venido a ella y estan vendiendo las cosas que han traido. . . ."

[90] *Ibid.*, p. 259: "pasajeros y tratantes . . . sacan muchos naturales sin liçençia del que govierna, e otros se van con ellos unos para el reino del Pirú otros para Chyle y el rio de La plata y es causa que se acaben los naturales destas provincias." See also statement made by Martin Delgadillo, Santiago del Estero, Nov. 3, 1589, *in* Gobernación del Tucumán, *op. cit.*, pp. 246–247: "este testigo a ydo y venido de las prouincias del peru a estas de tucuman muchas veces e a visto quese a sacado destas prouincias grandisima fuerça de yndios asy los encomenderos como los mercaderes e soldados . . . y siempre se les quedan en este Reyno del priú muchos de ellos. . . ."

[91] Statement of the teacher Francisco de Aguilar, Oct. 25, 1589, *in* Gobernación del Tucumán, *op. cit.*, pp. 243–244.

besides several rancherias.[92] The other original fifty-seven encomiendas around Rioja were similarly populated. P. Lozano expresses his astonishment at the enormous decrease of this aboriginal population.[93]. Even the memory of the names of the pueblos enumerated in the titles of the original encomiendas had disappeared by his time.

ECONOMIC LIFE IN THE COLONIAL PERIOD

With the conquest of the natives and the spread of Spanish influence over the whole of Tucumán, the economic situation of the area underwent a complete change. Hitherto the few towns had been centers of small isolated areas; they lived a self-sufficient life and the products of their weaving were the only articles they had to offer in the markets of Perú. During the last decades of the sixteenth century, however, the Spanish colonists began to take advantage of the increasing through-going traffic from the La Plata to Perú. This was particularly true of such towns as Jujuy, Salta, Tucumán, Santiago, and Córdoba, which represented halting places on the route from Buenos Aires to Perú, and in which the trade in mules and cattle received such a great impetus that it eventually became the main commercial activity of Tucumán.

In the mining districts of Perú the mule had become the principal pack animal for the transport of mineral ore, but the climatic conditions in the Peruvian highland were unfavorable to mule-breeding. The same was true in the case of cattle, for which the demand was strong in the mining districts. The vast Pampa of the La Plata, on the other hand, had an enormous surplus of stock. Tucumán thus became the natural intermediary between two areas which possessed supplementary resources. Only a few mules were raised in Tucumán itself, most of them being bred in the Pampa.[94] They were driven out at the age of two years, wintered one year in Córdoba, the next in Salta, and were then taken to work in the mines of Perú. The people

[92] Letter of the governor to P. Juan Fonte in which he reports on recent foundation of the town quoted in Lozano, P., Conquista del Rio de la Plata, vol. 4, pp. 395–397.

[93] *Ibid.*, p. 397: "causa justa admiracion ver cuánto se han minerado y consumido sin hallarse al presente memoria de los mas de aquellos pueblos que se registraron en los titulos primitivos de las encomiendas y los indios reducidos a muy poco número. . . ."

[94] Concolorcorvo, El Lazarillo de ciegos caminantes desde Buenos Aires a Lima, 1773 (Buenos Aires, Junta de Historia y Numismática Americana, 1908). Chapters 6 and 7 contain a detailed statement on the colonial mule trade.

of Tucumán were more than mere traders in mules. They received the mules from the Pampa in an almost wild state and it was their task to break them in before they sold them to Perú. The inhabitants of certain valleys became particularly skilful as *domadores* and to a certain extent have preserved this expertness down to the present time.

Thus, by the first half of the seventeenth century the economic activities of the whole population of Tucumán were centered in the mule trade, and the effect of the new economic situation on the different Spanish settlements soon became visible. During the first half-century of Spanish colonization, Santiago del Estero had been the undisputed urban center of Tucumán,[95] but with the development of traffic and the mule trade, other towns located along the lines of travel developed at the expense of Santiago. Córdoba, especially, located at the very border between the Pampa and Tucumán, obtained the major part of the advantages accruing from the new economic situation.

As early as 1657 the inhabitants of Córdoba were reported to be "rich in Gold and Silver, which they get by the Trade they have for Mules, with which they fournish Peru and other parts; which is so considerable that they sell about 28 or 30000 of them every year . . ."[96] Acarete reports: "the People of Cordoua drive a trade in Cows, which they have from the country of Buenos Ayres, and carry to Perú . . . This Kind of Traffick makes this Town the most considerable in the Province of Tucuman, as well for its Riches and Commodities, as for the number of Inhabitants which are counted to be at least 5 or 600 Families besides Slaves who are three times the number."[97] In 1690 the episcopal see was transferred to Córdoba, the Jesuits established their headquarters in the town, and a university was founded. At the end of the eighteenth century the town had numerous well built houses, churches, and monasteries, and the basis of all its wealth was still the mule trade.

Next to Córdoba, Salta felt the advantage of the increasing trade. As early as 1657 the town had "about 400 Houses and 5 or 6 Churches

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[95] Royal decree conceding the title of "ciudad" to Santiago d. E., Madrid, March 22, 1577, *in* Gobernación del Tucumán, *op. cit.*, pp. 478–479. Royal decree conceding title of "muy noble" to Santiago d. E., San Lorenzo, Feb. 19, 1577, *ibid.*, pp. 474–475. Royal decree conceding coat of arms to Santiago d. E., San Lorenzo, Feb. 19, 1577, *ibid.*, pp. 476–477.

[96] Acarete de Biscay, Account of a voyage up the River de la Plata and thence over land to Perú, p. 29 (London, 1698).

[97] *Ibid.*, p. 31.

and Convents." It was "a place of great resort because of the considerable Trade . . . in Corn, Cattle, Wine, Salted Meat, Tallow . . . wherewith they trade with the Inhabitants of Peru."[98] Its importance as a trading center continued to increase. The larger part of its business affairs passed into the hands of "gallegos" but the great fair of Salta attracted merchants from all Tucumán as well as Perú, who were interested in the mule trade.[99]

The Spanish settlements in the northeast, on the other hand, remained at a standstill and even went into decay. In the second half of the eighteenth century, Santiago del Estero, Jujuy, and San Miguel del Tucumán, all together, were not equal to either Córdoba or Salta.[100] Even Esteco (fig. 4) eventually disappeared: "This town was formerly as big and as considerable as Cordoua, but is now (1657) ruined, there being above 30 families left in it, for the rest deserted it."[101] In 1692 an earthquake caused the complete abandonment[102] of this town, the ruins of which still exist.

Santiago also fell into decay owing to its less favorable location in regard to through-going traffic and trade. The Santiagueños were still considered the best soldiers of Tucumán but there was no field for further warlike activities within the limits of Tucumán, and from the frontier war which they carried on with the wild Indians of the Chaco, they reaped but little profit.[103] The town continued to decline in importance, so that by the second half of the eighteenth century the number of families who lived in decent houses was less than twenty; the rest of the inhabitants lived in huts.

The modest prosperity of San Miguel del Tucumán was largely based on traffic. The inhabitants had abundant wood in their forests, which they used in the making of heavy two-wheeled wagons, and, in addition, they raised and trained the bulls to draw them through the plains. Just as Mendoza in the Cuyo area was the home of a numerous group of *carreteros* who specialized in bull and cart traffic between that town and Buenos Aires, so the people of Tucumán were largely employed in traffic between Perú and the La Plata.[104]

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[98] *Ibid.*, p. 35.

[99] Concolorcorvo, *op. cit.*, pp. 87–93.

[100] *Ibid.*, p. 138.

[101] Acarete, *op. cit.*, p. 34.

[102] Lozano, P., Historia de la conquista del Paraguay, Rio de la Plata y Tucumán, vol. 1, p. 183 (Buenos Aires, 1873).

[103] A small tax was levied at Salta for each passing mule for the defense of the Chaco frontier (Concolorcorvo, *op. cit.*, p. 97).

[104] Concolorcorvo, *op. cit.*, pp. 70–87, gives a detailed description of this form of traffic.

Besides the five most important urban settlements located on the route from the La Plata to Perú, and some minor villages, there were certain settlers on larger or smaller estates, living principally on the returns from stock raising or trade in stock. Their dwellings, of which the *ramada* was the prevailing type,[105] were extremely poor. Jerked meat was the only food where, in times previous to the Spanish conquest, an aboriginal population lived almost entirely on agriculture.

TUCUMAN IN THE MODERN PERIOD[106]

The cultural landscape of Tucumán of the second half of the sixteenth century was characterized by the existence of a few isolated, self-sufficient, Spanish colonies, which could hardly maintain themselves in the midst of the hostile aboriginal population. During the following centuries the area played the important rôle of intermediary between the stock-raising Pampa of the La Plata and its best market, the mining districts of Perú. The prosperity which stock trading brought to the area was largely centered in Córdoba and Salta.

The fundamental change which the Pampa underwent after the last decades of the nineteenth century reflected on the Tucumán area. From a sparsely settled, purely stock-raising country, the Pampa rapidly passed, with the development of agriculture, into a comparatively densely populated area, and became by far the most productive landscape of South America. Mule trade to Perú became an insignificant item; export was directed to Europe. And the Pampa, once a poor country, became now a powerful market which offered to the neighboring Tucumán unexpected economic chances.

The development of modern Tucumán in every respect, economic as well as cultural, the growth of its urban and rural settlements, has become fully controlled by the influence of the neighboring Pampa. The last economic phase which the Pampa (and, indirectly, Tucumán) entered, favored the different parts of Tucumán in different ways. Córdoba and the surrounding plains took part directly in the agricultural expansion, the fields extending from the La Plata right to the foot of the Sierra de Córdoba, where increasing aridity draws the

[105] *Ibid.*, p. 143. R. Lehmann Nitzsche has made a study of this primitive type of dwelling—a branch hut—used by the stock-raising population of Argentine. *See* Folklore Argentino. VI. La ramada. Boletín Academia Nacional de Ciencias, vol. 23, pp. 610–628 (Córdoba, Arg., 1919).

[106] An excellent geographical analysis of the different parts of the modern Tucumán area has been given by Dénis, P., The Argentine Republic (New York, 1922).

border line. Large parts of the province of Córdoba, formerly devoted to primitive stock raising, were transformed into prospering farms and estates worked by European immigrants, mostly Spaniards and Italians. A great irrigation project now accumulates the water of the Rio Primero and transforms the land around Córdoba into a green oasis of gardens and orchards. The Sierra de Córdoba itself, once considered a worthless mountain good enough for goat and sheep raising, developed numerous health resorts. The high elevation of the mountain attracted the wealthier classes of the urban settlements of the Pampa during the summer months. Highways connect modern little towns and a railroad crosses the mountain.

The growing wealth of the increasing rural population kept pace with the growth of the city. Córdoba increased rapidly in population, yet it reflects today its colonial past. The beautiful, baroque cathedral, churches, and monasteries, the former residence of the viceroy, and many a house still recalls in its style the colonial times in which stock trading and breeding produced the wealth of the inhabitants. Out of the colonial nucleus of the settlement are growing, now, several-storied business houses and hotels, which somewhat obliterate the colonial character of the down-town quarter. The ranchería, the primitive, grass-thatched, adobe huts of the Indian and half-breed population have disappeared from the interior of the rapidly growing settlement. Ranchos and complete rancherías are now to be found only on the outskirts of the town. The settlement thus contains, at present, all architectural elements, ranging from the primitive Indian dwelling to the colonial mansion, church, and modern building of several stories.

Among the urban settlements, the city of Tucumán has become the most prosperous. Its climate is particularly adapted to the growth of sugar cane; with the increasing population of the Pampa the sugar plantations have extended and modern manufactories have appeared. The industry has attracted no foreign immigration; the less favored parts of the interior have provided the necessary labor.

All other parts of ancient Tucumán were less affected by the general development. They still reflect to a large extent colonial conditions. Yet the whole area, the economic life of which was for centuries oriented toward the highland of Perú in the north, is now fully under the influence of the Pampa in the southeast, and, economically as well as culturally, completely incorporated into the Argentine Republic.

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GRAPHIC STUDIES IN CLIMATOLOGY

II. THE POLAR FORM OF DIAGRAM IN THE PLOTTING OF THE ANNUAL CLIMATIC CYCLE*

BY

JOHN B. LEIGHLY

I

It is customary, in the graphic representation of the change in the value of a climatic element in time, to use the generally appropriate method of rectangular coordinates, with time plotted on the horizontal axis. The method is logically correct, when the time sequence involved is a segment of the current lapse of time, as a certain month, year, or series of years. But when the time sequence is instead the ideal daily or yearly cycle in which the *mean* values of the climatic element vary, the linear representation of the time variable is logically false: the ideal cycle returns to the beginning, and repeats itself indefinitely. The idea of representing this cycle as an angle of 360°, or, in the polar form, the climatic element considered as a vectorial quantity, suggests itself. Efforts in this direction have not been wanting. Besides numerous polar-type figures scattered through climatologic literature, the writer knows of two articles describing the type and asserting its superiorities. An older statement[1] presents an eloquent defense of the method:

> If graphic expressions are to represent translations of processes in time into the field of space, they should serve not only to make plainer and more easily understood the phenomena they elucidate, but, in so far as an intimate relation exists between space and time, it may also be expected that the figure presented to the sight be geometrically analogous to the time process represented. I believe therefore that the variations of temperature during a year, which heretofore have been represented by ascending and descending lines on a progressive (*fortlaufende*) surface, can in accordance with the above be made clearer by closed curves.

* Graphic Studies in Climatology. I, present volume, No. 3.

1 Friedman, S., Graphische Darstellung der jährlichen Temperatur eines Ortes durch geschlossene Curven, Mitt. d. k.-k. geogr. Gesell. in Wien, vol. 6, pp. 244–246 (1862). Citation from p. 244.

In recent years a similar effort has been presented by E. N. Munns,[2] with numerous illustrations, for the correlation of climatic data with the distribution of vegetation.

In the present paper the polar form of diagram is examined with reference to its inherent peculiarities, and to its adaptation to the

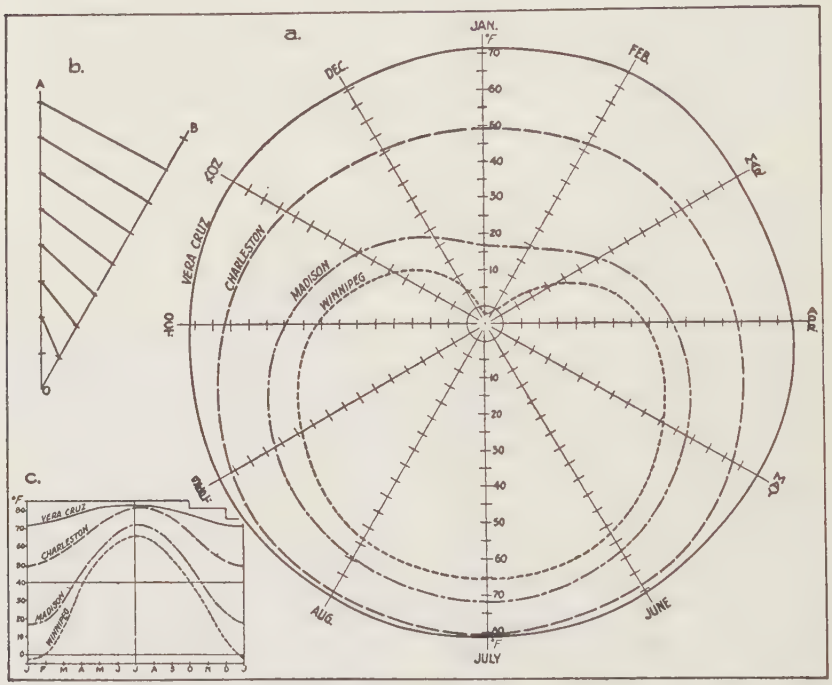


Fig. 1.

graphic display of the annual climatic march. Attention is given to the two conventions by which useful graphic effects are produced: the curve, whose effect is produced by its course through the field of coordinates, and secondarily, in the polar chart, where it is closed, by its radius; and the surface, whose primary graphic quality is area, whose secondary is form. In the two cases the handling of numerical material must proceed in a manner different from that used when plotting is done on rectangular coordinates. In order that a curve plotted in polar coordinates may represent solely the sequence of the numerical quantities used, a procedure analogous to the conformal projection of maps must be followed; and in the plotting of a cumu-

[2] Climatic phenomena, Monthly Weather Review, vol. 50, pp. 477–481 (1922). Indexed under the title "The climatograph. A new form of chart for climatic phenomena."

lative element, such as precipitation, where the area of the figure is critical, the radii vectores of points on its periphery must be adjusted according to the fundamental principles of equivalent mapping. Fortunately for practical use, the mathematics of the present case is much simpler than that involved in the plane representation of the earth's surface.

The element most frequently delineated in climatic graphs is temperature: as a fluctuating quantity, the continuous curve, plotted against time and a temperature scale, is its appropriate symbol. In the polar graphs of temperature seen in the literature, it is plotted as in fig. 1*a*: time is the vectorial angle, temperature the vector; a linear scale is used on the month-radii, such as is used in rectangular coordinates. In the figure, the temperatures of four North American stations are plotted: Vera Cruz, a station on the border of the tropics, with but a slight range of temperature through the year; Charleston (S. C.), a mesothermal climate with moderate range and symmetrical march; Madison (Wis.) and Winnipeg, microthermal climates, of which Winnipeg is the more continental, and has the lower mean temperature. On the figure, a general lowering of temperature and an increasing annual range are reflected in the closed curves by a progressive flattening in the winter half of the curve, until in the more continental stations there is a marked reentrant in midwinter, so that the curve takes on a cardioid form. This peculiarity is accepted by the authors quoted. Indeed, Friedman uses the cardioid form of the curve as a distinguishing feature (*loc. cit.*, p. 244): " . . . . the curves for places in the intermediate and polar zones possess convex apices on the summer side, and heart-shaped reentrants on the winter side." Munns (*loc. cit.*, p. 477) states that "when temperatures are below 20° [Fahr.; which temperature he uses as the pole of his graphs] it is necessary to plot the points below the center, rather than above it, in order to complete the figure." Such a procedure of course distorts the curves even more than is the case in figure 1*a*, where the center is —10° F. These differences in form correspond to no differences in the actual march of temperature, as may be seen by figure 1*c*, where the same data are plotted on rectangular coordinates. There the only easily recognizable differences among the curves consist in an increasing amplitude, and a lowering of the mean position of the curve, from Vera Cruz to Winnipeg.

The reason for the greater part of the distortion of the curves may be seen by figure 1*b*. The radii *OA* and *OB* are divided into equal

parts, as are the month radii in figure 1*a*, and the lines joining points on OA and OB represent curves with a constant difference between two consecutive months equal to that represented by one of these divisions. The closer the curve lies to the center of the figure, the greater is the change in the slope of the curve. The form of the temperature curves in figure 1*a* is obviously affected by this feature of the diagram. The construction of a graph in which only the peculiarities of the temperature march are reflected requires such a graduation on the month radii that equal changes in temperature from month to month are reflected in the curve by equal changes in slope.

II

Such a graduation may be arrived at by construction. In figure 2*a*, the two radii OA and OB are drawn so as to include the angle α at O. Oa_0, of any convenient length, is laid out along OA, and a_0b_0 drawn at right angles to OA. The length Ob_0, measured from O, is laid off on OA, extending to Oa_1; a_1b_1 is drawn at right angles to OA, and hence parallel to a_0b_0. Ob_1 is laid off on OA, establishing the point a_2. The line a_2b_2 is drawn in the same manner as a_1b_1, and the procedure repeated as far as desired, establishing along OA a series of points a_0, a_1, a_2, etc. If the lengths Oa_0, Oa_1, Oa_2, etc., are laid off along any other radius OC, making the angle OAC with OA at O, and the series of lines a_0c_0, a_1c_1, a_2c_2, etc., be drawn, these lines are parallel, since they cut two lines, OA and OC, into mutually proportional parts, and form with them similar isosceles triangles.

The relation existing among the members of the series of lengths Oa_0, Oa_1, Oa_2, etc., is simple. In the right triangle Oa_0b_0.

$$Ob_0 = Oa_0 \tan \alpha, \text{ in triangle } Oa_1b_1$$
$$Ob_1 = Oa_1 \tan \alpha, \text{ in triangle } Oa_2b_2$$
$$Ob_2 = Oa_2 \tan \alpha, \text{ etc.}$$

Since $Oa_1 = Ob_0$, $Oa_2 = Ob_1$, $Oa_3 = Ob_2$, etc.

$$Oa_1 = Oa_0 \tan \alpha,$$
$$Oa_2 = Oa_0 \tan^2 \alpha,$$
$$Oa_3 = Oa_0 \tan^3 \alpha, \text{ and so on.}$$

The series of lengths Oa_0, Oa_1, Oa_2, etc., is thus a geometric progression, in which the first term is Oa_0, and the constant ratio $\tan \alpha$. Since in such a series the relation of one term to those above and below it is the same, whatever its position in the series, lines such as

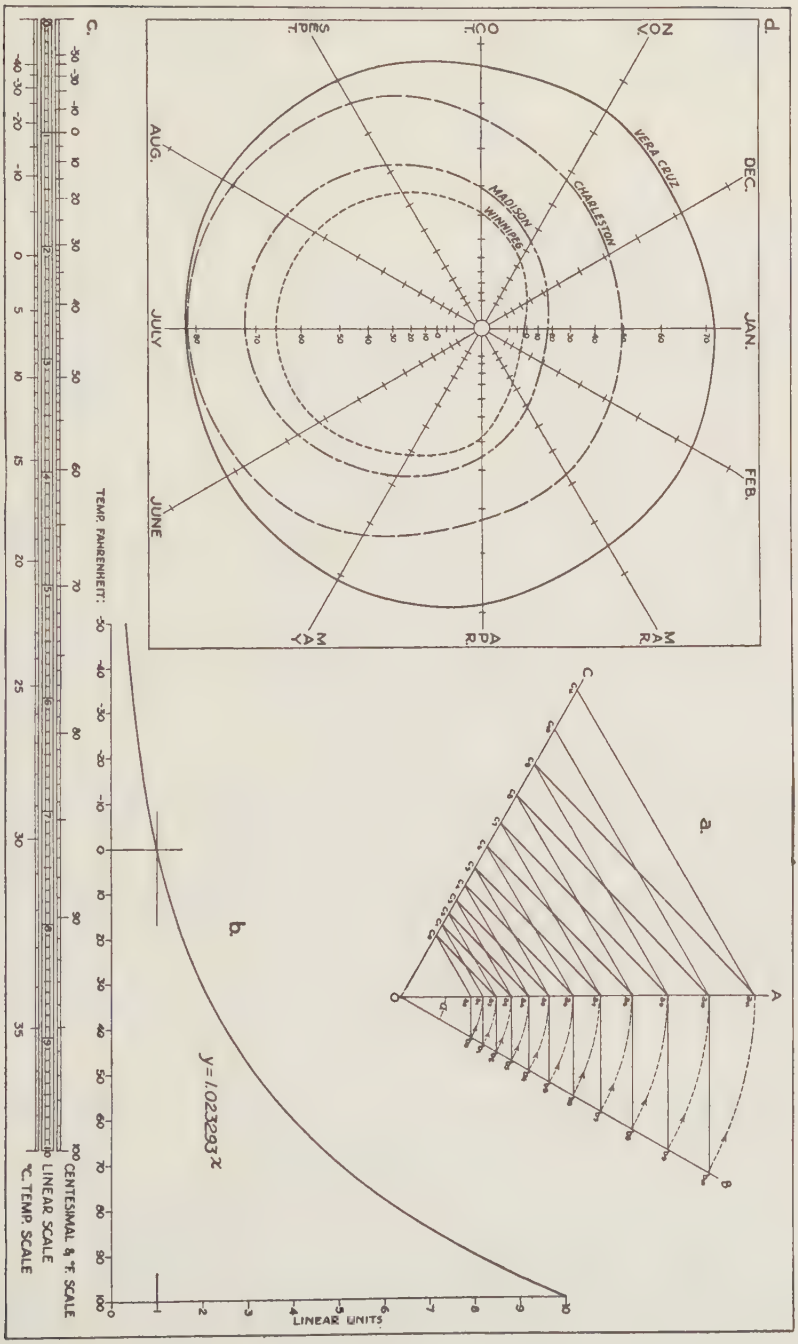

a.
b.
y=1.023293x
LINEAR UNITS
c.
TEMP. FAHRENHEIT:
CENTESIMAL & °F. SCALE
LINEAR SCALE
°C. TEMP. SCALE
d.
VERA CRUZ
CHARLESTON
MADISON
WINNIPEG
JAN.
FEB.
MAR.
APR.
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.

Fig. 2.

a_2c_0, a_3c_1, a_4c_2, etc., in figure 2*a* (recognizable by a constant difference between the subscripts), joining points on adjacent radii having a constant nominal difference in the series, will cut the radii proportionally, and thus be parallel. The graduation for the plotting of temperatures on the polar form of chart, such that the slope of a curve is independent of the distance of the points of intersection of the curve with the radii from the pole, is therefore the sort of series just defined: the successive points on the graduation lie at distances from the pole which form a geometric progression, the first term having any assigned value, and the constant factor being the tangent of the angle between adjacent radii. But since the quality of the graduation was seen to be independent of the magnitude of the included angle, and since the tangents of angles between 0° and 90° take all values between zero and infinity, any positive number may be used as constant factor in the devising of a scale. If a number greater than 1 is used, the series will be increasing; if a fractional number, decreasing. Either procedure will lead to the desired result, but it will be convenient to make the series increasing, as that in figure 2*a*.

For computing and plotting, it will be convenient to contrive a scale of 100 divisions, with a total length of 10 linear units. The constant ratio of such a series will be given by the use of the equation

$$r_u = r_0\ k^{n-1}, \tag{1}$$

if r_u represent the length of the last term, r_0 that of the first term, k the constant factor, and n the number of terms. The first term will be taken as 1, and the terms designated r_0, r_1, r_2, r_3 . . . . . r_{100}. The number of terms will then be 101. The equation will then appear as

$r_{100} = 1 \cdot k^{100}$, or, since the last term has the length 10,

$$10 = k^{100},$$
$$k = \sqrt[100]{10.}$$

Put in terms of logarithms,

$$\log k = 1/100, \text{ or } 0.01,$$
$$k = 1.023293.$$

It is not necessary, however, to use the numerical value of k in determining the radius vector for any temperature. For since it is agreed that the first term be denominated r_0, the exponent n–1 in equation (1) becomes, for any term in the series, say r_m, the same as the subscript of r:

$$r_m = k^m; \text{ and}$$
$$\log r_m = m \cdot 0.01.$$

To plot any temperature on this scale, it is only necessary to multiply the temperature by 0.01, and in a table of logarithms or antilogarithms find the number whose logarithm is thus found:

$$r_m = \text{antilog } (m \cdot 0.01).$$

For example, if m is 60° F., log $r_m = 0.6$, $r_m = 3.981$.

The series $r_0 = 1$, $r_{100} = 10$, is well adapted to the plotting of temperatures in degrees Fahrenheit, since the upper limit is at about the upper limit of the range of mean monthly temperatures. Some mean monthly temperatures, however, lie below zero F., and hence the series must contain values of r for negative values of the subscript of r. It is easily shown that

$$r_{-m} = 1/10\ r_{100-m},$$

and that the series is continuous below zero, the pole of the figure representing negative infinity. In figure 2*b* the values of r corresponding to Fahrenheit temperatures between —50° and 100° are plotted. As is seen, the graph of the lengths of r is an exponential curve, with base 1.023293. On this account, the scale will for the sake of brevity be referred to below as the exponential scale.

A congruent scale for Centigrade temperatures is most easily obtained by changing the C. temperatures to F. by the use of easily accessible tables, and taking the value of r from a table of logarithms. An independent scale, not congruent with the F. scale plotted in figure 2*b*, may be obtained, while retaining the range of 100°, necessary for the convenient determination of r, by using as limits the temperatures of —60° and 40° C., which include all mean monthly temperature values recorded for the earth. Calling, for purposes of computation, —60° zero, 40° one hundred,

$$r_{m° \text{ C.}} = \text{antilog } \overline{0.01\ [100 - (40 - m° \text{ C.})]}.$$

The determination of log m can be done by inspection, and the value of r read from a table of logarithms or antilogarithms. For the drawing of small figures such as are shown in this paper, where the units of length used in plotting were usually centimeters, slide rule results are sufficiently accurate. The figures here presented are based on values found by setting temperatures (to the first decimal of degrees) on the "L" scale of a 40-centimeter slide rule, and reading r on the "D" scale. In figure 2*c* linear values of r on the F. temperature scale and the congruent C. scale are compared with a linear scale.

Figure 2*d* is a diagram similar to figure 1*a*, except that the scale of temperatures along the month radii is the exponential scale instead of the linear. Temperatures are in F. degrees. The curve for Vera Cruz is not notably changed, since there is but little difference among the temperatures of the several months. Charleston's curve is more nearly circular than in the preceding figure. The reentrants in the curves for Madison and Winnipeg have disappeared, and only a slight flattening in the winter portion of the curves disturbs their generally circular form. The construction gives assurance that the peculiarities of the curves are due to the actual temperature march alone. But the approach of the curves to the circular form prompts a query as to the significance of the circle in such a plotting of temperatures, and of the departures from true circularity. It becomes advisable to examine the general features of the annual temperature march, in order to interpret the peculiarities of the curves plotted.

III

The qualities of the annual temperature march are thus summed up by Köppen:[3] "The annual march of the temperature of the air at different stations differs (*a*) in absolute height, (*b*) in amplitude, and (*c*) in form and attitude of the temperature curve." A method of analyzing the temperature march of stations in the intermediate latitudes is given in the same article: "In order to obtain *c* independently of *a* and *b*, we take the mean temperature of the coldest month as zero, and divide the excess of the other monthly means over this by the difference between the warmest and coldest months. The latter is an indeed approximate, but adequate, expression of the amplitude of the annual curve. . . . ." The quantities thus obtained are the "month-factors" of the temperature of the station in question. In a later communication[4] the same author elaborates the method, and uses, as a standard of comparison for all annual curves, the sine curve based on the difference between the temperatures of the extreme months. The procedure may best be illustrated by an example.

The mean temperatures for the months, of two of the stations used in figures 1 and 2, Charleston and Madison, are as follows:[5]

[3] Met. Ztsch., vol. 39, p. 387 (1922).

[4] Der jährliche Temperaturgang in den gemässigten Zonen und die Vegetationsperiode, Met. Ztsch., vol. 43, pp. 161–172 (1926).

[5] U. S. D. A., Weather Bureau, Climatological data for the United States by sections. The data are based on a 54-year record for Charleston, a 58-year record for Madison.

TABLE 1

(Degrees F.)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Charleston	49.9	52.4	57.4	64.5	72.7	78.9	81.3	81.0	76.6	67.8	58.1	51.7
Madison	16.7	19.1	30.6	45.4	57.6	67.2	72.1	69.8	62.4	50.3	35.2	22.8

And the differences between the minimum (January) temperature and those of the other months:

TABLE 2

(Degrees F.)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Charleston	00.0	2.5	7.5	14.6	22.8	29.0	31.4	31.1	26.7	17.9	8.2	1.8
Madison	00.0	2.4	13.9	28.7	40.9	50.5	55.4	53.1	45.7	33.6	18.5	6.1

When expressed as percentages of the range between the temperatures of the extreme months, these become:

TABLE 3

(Per Cent)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Charleston	00.0	8.0	23.9	46.5	72.6	92.0	100.0	99.1	85.0	57.0	26.1	5.7
Madison	00.0	4.3	25.2	51.8	73.8	92.2	100.0	95.8	82.5	60.7	33.4	11.1

These are the "month-factors" used by Köppen in the elucidation of the features of the annual temperature march enumerated under his heading "*c*," in the computation of which "absolute height" and "amplitude" are eliminated. By the computation of differences between these values and those of any standard march, peculiarities in the march of any station may be made plain.

The simplest standard for comparison is the sine curve. A set of factors ranging between 0.0 and 1.00, functions of the phase angle θ, and with a symmetrical march, may be obtained by computing $\sin^2 \frac{1}{2}\theta$. Following are these factors for successive angles between 0° and 360°, at intervals of 30°:

TABLE 4

θ:	0°, 360° (Jan.)	30° (Feb.)	60° (Mar.)	90° (Apr.)	120° (May)	150° (June)	180° (July)	210° (Aug.)	240° (Sept.)	270° (Oct.)	300° (Nov.)	330° (Dec.)
$\sin^2 \frac{1}{2}\theta$:	0.0	0.067	0.250	0.500	0.750	0.933	1.000	0.933	0.750	0.500	0.250	0.067

Expressed as percentages, these may be compared directly with the values in table 3.

If the ranges between the temperatures of the warmest and coldest months at the stations Charleston (range 31.4° F.) and Madison (range 55.4° F.) be multiplied by these factors, the products will be the series of differences within the sine series corresponding to the actual differences of table 2:

TABLE 5

(Degrees F.)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Charleston	0.0	2.1	7.8	15.7	23.6	29.3	31.4	29.3	23.6	15.7	7.8	2.1
Madison	0.0	3.7	13.9	27.7	41.6	51.7	55.4	51.7	41.6	27.7	13.9	3.7

These values may, of course, be compared with the actual differences in table 2; they include the amplitude of the temperature march as well as "form and attitude." By adding them to the respective minima, the sine series of temperatures between the extremes is obtained:

TABLE 6

(Degrees F.)

Charleston	49.9	52.0	57.7	65.6	73.5	79.2	81.3	79.2	73.5	65.6	57.7	52.0
Madison	16.7	20.4	30.6	44.4	58.3	68.4	72.1	68.4	58.3	44.4	30.6	20.4

The quantities presented in table 6 may be compared directly with the actual temperatures, either numerically or graphically, with respect to all the qualities of the temperature march. In figure 3*a* the

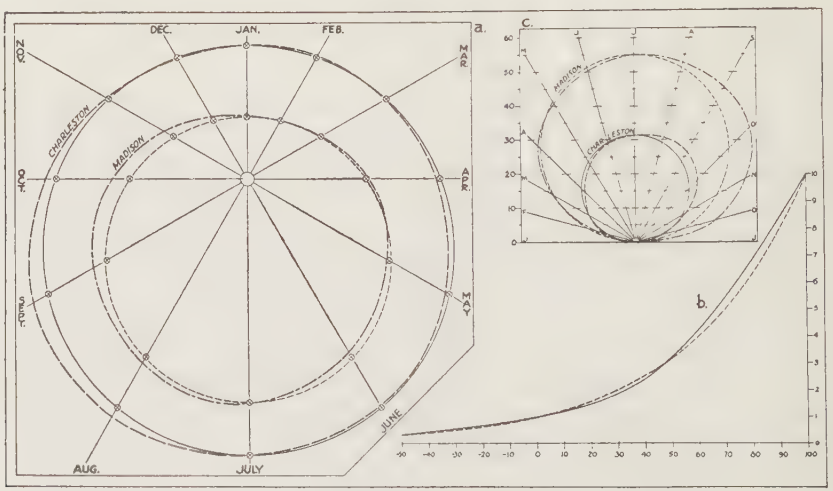


Fig. 3.

actual temperatures of the two stations (heavy lines), and the values of table 6 (small circles with cross within them) are plotted on the exponential scale. In addition, circles are drawn through the points of maximum and minimum of the two stations, with radius equal to $\frac{1}{2}(r_{max} + r_{min})$, r_{max} being the radius vector of the temperature of the warmest month, r_{min} the same for the coldest, and passing through the plots of t_{max} and t_{min}.

As is seen in the figure, the sine series of temperatures between a pair of extremes, when plotted on polar coordinates by the exponential

scale, lie very nearly, but not quite, on a circle passing through the plots of the extremes. In most of the plots, the points representing the sine series appear to lie on the circle; but on the curve for Madison the departure is noticeable in about half the months. As will appear below, the removal of this small discrepancy involves the sacrifice of the ease of construction and general utility of the polar form of chart with the exponential scale along the month radii. When temperatures are plotted on such a chart, a standard for comparing the actual temperature march with the symmetrical sine series is obtained simply by drawing a circle through the points of maximum and minimum, with center on the Jan.–July axis, halfway between the plots of the January and July temperatures. No computation is therefore necessary for the examination of all the qualities of the curve.

IV

The amount of divergence of the sine series from a circle may be determined by the computation of the radii vectores in the circle, at intervals of 30°. In the computation below, the initial side of the vectorial angle is the January radius, and the angle is considered positive as increasing through the successive months (clockwise in the diagrams). The radii vectores for the circular curve may be computed by the following equation of the circle in polar coordinates, when the center lies on the polar axis:

$$r^2 - 2r'r\cos\theta = R^2 - r'^2. \qquad (2)$$

In this equation r, θ, are the polar coordinates of any point on the circle, r' the radius vector of its center, and R its radius; r' will be negative, since the center lies on the side of the pole toward the maximum. If the radii vectores of the points of maximum and minimum temperatures be designated r_{max} and r_{min} respectively,

$$R = \tfrac{1}{2}(r_{max} + r_{min}),$$
$$r' = r_{max} - R = \tfrac{1}{2}(r_{max} - r_{min}).$$

When these values are substituted in equation (2), and the equation solved for r,

$$r = \frac{-\cos\theta\,(r_{max} - r_{min}) \pm \sqrt{\cos^2\theta\,(r_{max} - r_{min})^2 + 4r_{max}r_{min}}}{2}. \qquad (3)$$

The positive root of the second term of the numerator gives r for θ and $360° - \theta$, the negative root r for $180° - \theta$ and $180° + \theta$. In the

following tables the values of r computed by this equation are presented for comparison with the lengths of the radii vectores corresponding to the sine series of temperatures (table 6) on the exponential scale:

TABLE 7

CHARLESTON

	0°, 360° (Jan.)	30°, 330° (Feb., Dec.)	60°, 300° (Mar., Nov.)	90°, 270° (Apr., Oct.)	120°, 240° (May, Sept.)	150°, 210° (June, Aug.)	180° (July)
r by exp. scale	3.155	3.312	3.776	4.529	5.433	6.194	6.500
r on circle	3.155	3.310	3.769	4.529	5.441	6.199	6.500

TABLE 8

MADISON

	0°, 360° (Jan.)	30°, 330° (Feb., Dec.)	60°, 300° (Mar., Nov.)	90°, 270° (Apr., Oct.)	120°, 240° (May, Sept.)	150°, 210° (June, Aug.)	180° (July)
r by exp. scale	1.469	1.600	2.023	2.780	3.828	4.831	5.260
r on circle	1.469	1.587	1.989	2.780	3.884	4.870	5.260

The differences can be detected only on carefully made drawings. They increase with increasing range of temperature. For the extreme case, not attained among the temperatures of the earth, of $t_{max} = 100°$ F., $t_{min} = 0°$, the radii vectores of the circle are plotted in figure 3*b* (full line) for comparison with the graph of the exponential scale (dashed line). All curves representing the sine series as a circle will fall between the two curves, if the radii for the extreme temperatures lie on the exponential curve. No scale may be devised which will represent the sine series for all pairs of extreme temperatures as a circle, since r for any temperature is a function of t_{max} and t_{min} of the series to which it in any given case belongs.

It is possible, however, to arrive at a rigorous solution of the problem of plotting the monthly temperatures of a given series in such a way that the circle drawn on the diagram will represent, for comparison, the symmetrical sine series between the given extremes.

It is obvious that the circle whose equation is (3) above contains points whose radii vectores have all possible values between r_{min} and r_{max} of any series, in two sets, one between 0° and 180°, that is, in the ascending limb of the curve if plotted on rectangular coordinates, and one between 180° and 360°, or in the descending limb. Moreover, the equation for the sine series of temperatures between t_{min} and t_{max} of any series,

$$t = t_{min} + \sin^2 \tfrac{1}{2}\theta\,(t_{max} - t_{min}), \qquad (4)$$

gives all values of t between the maximum and minimum. An appropriate value of r for any temperature between the extremes may be

found by equation (3), by finding first, with the aid of (4), the phase angle at which it occurs in the sine series. The series of temperatures in table 6 are merely those whose phase angles are multiples of 30°, between 0° and 360°. The values of r corresponding to the actual temperatures may be compared with r for these special intervals of θ which are the month angles on the diagrams.

If in equation (4) $\sin^2 \frac{1}{2}\theta$ be replaced by its equivalent $\frac{1-\cos\theta}{2}$, the equation may be solved so as to give the phase angle corresponding to any value of t:

$$\cos\theta = 1 - \frac{2(t - t_{\min})}{t_{\max} - t_{\min}}. \qquad (5)$$

If $\cos\theta$, together with the values of $r_{\max}$ and $r_{\min}$, be then substituted in (3), r for the particular temperature may be found. When the series of values of r are then plotted on the appropriate month radii, the circle drawn through the extreme points will cut off on each radius the radius vector corresponding to the temperature in the sine series, for comparison with the temperature plotted. The computation of r is rather laborious. In the following the radii vectores for the temperatures of the two stations Charleston and Madison are tabulated, (*a*) as derived directly on the exponential scale, (*b*) as computed by equations (3) and (5), $r_{\max}$ and $r_{\min}$ being taken as on the exponential scale:

TABLE 9

CHARLESTON

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
a)	3.155	3.341	3.750	4.415	5.331	6.151	6.500	6.456	5.832	4.765	3.820	3.280
b)	3.155	3.341	3.738	4.409	5.348	6.163	6.500	6.460	5.852	4.771	3.799	3.284

TABLE 10

MADISON

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
a)	1.469	1.553	2.023	2.744	3.767	4.699	5.260	4.989	4.207	3.184	2.249	1.690
b)	1.469	1.566	1.989	2.856	3.826	4.748	5.260	5.017	4.272	3.213	2.221	1.670

The differences are of course of the same order of magnitude as those of tables 7 and 8, where the radii vectores of the sine series, instead of those of actual temperatures, were discussed. In figure 4*a* the lengths of tables 9 and 10 are plotted (heavy lines), and the circles through the maxima and minima (light full lines), here strictly comparable with the graphs of temperatures, are drawn. The slight difference between the result of this procedure and the use of the exponential scale may be seen by comparing the figure with figure 3*a*.

Since in the above r_{max} and r_{min}, which enter as arguments in the computation, were determined according to principles independent of the remainder of the computation, these may have any convenient value. The most obvious procedure is to plot these on a linear scale, or, in other words, to set $r_{max} = t_{max}$, $r_{min} = t_{min}$. Equations (3) and (5) will then be expressed wholly in terms of temperature, and may be combined, by introducing into (3) the equivalent of cos θ in (5). Equation (3) then reduces itself to

$$r = \frac{2t - (t_{max} + t_{min}) \pm \sqrt{(t_{max} + t_{min} - 2t)^2 + 4t_{max}t_{min}}}{2}. \qquad (6)$$

The computation by this equation is easy. The first term of the numerator and the first term under the radical are the same, except

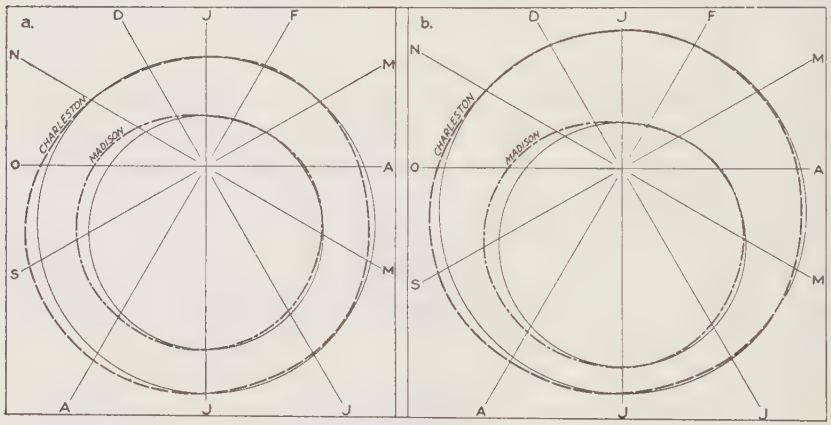


Fig. 4.

in sign. The sign of operation before the radical, for purposes of plotting, may be considered plus. All multiplications, divisions, squaring, and extractions of root may be performed by slide rule, even though large numbers appear under the radical, since no more than three significant figures need appear in the results. The data in the following table were computed thus, and are plotted, with the comparable circle, in figure 4*b*:

TABLE 11

Linear Units

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Charleston	49.9	51.8	56.0	62.6	71.2	78.3	81.3	80.9	76.4	66.3	56.6	51.7
Madison	16.7	17.7	23.6	35.7	50.3	64.3	72.1	68.4	57.1	41.1	26.7	19.3

The procedure indicated in equation (6) is that by which the temperature curve is most easily compared graphically with the sine series. But in addition, it permits, in a diagram, an accurate com-

parison of the other features of the annual march as well. "Absolute height" of the curve is represented in the figure, and range as well: the radius of the circle passing through the points of maximum and minimum is the mean of the symmetrical march, $\frac{1}{2}(t_{max} + t_{min})$; and the eccentricity of the curve, measured by the length of the radius vector of the center of the circle, is one-half the range of the symmetrical series, $\frac{1}{2}(t_{max} - t_{min})$, on the scale of the diagram. Comparison of figures 4*a* and 4*b* shows how much more plainly the major features of the annual march appear when plotted according to equation (6) than when the exponential scale is used. Contrasts in these qualities are subdued in 4*a*, while they appear in their full effect in 4*b*. For stations which have no negative temperatures in the annual march, this type of diagram displays the peculiarities of the temperature march better than any other. Where negative temperatures are to be plotted, some further manipulation will be necessary, such as taking a computing zero low enough to make all temperatures positive.

V

If the temperature series be considered wholly in terms of differences, so that $t_{min} = 0$, $r_{min} = 0$, the closed curve (and the cognate circle representing the sine series) will pass through the origin, and the equation of the circle becomes

$$r = -\cos\theta\ r_{max}.$$

The procedure is simplified by plotting the graph within 180°, and on the positive side of the origin. The phase angles for the months then have intervals of 15°. The sine series of temperatures is given by

$$t = \sin^2\theta\ (t_{max} - t_{min}).$$

If r_{max} be set equal to t_{max}, and the figure be drawn as in figure 3*c*, with the phase angles of the successive months increasing clockwise from the left side of the figure, r_{max} falling at 90°,

$$r = r_{max} \sin\theta.$$

And, to find r for any temperature t, putting $t'_{max} = t_{max} - t_{min}$,

$$r : t = r_{max} \sin\theta : \sin^2\theta\ t'_{max},$$

$$r = \frac{t}{\sin\theta} = t \operatorname{cosec}\theta.$$

The points of division on the radii, as is seen in figure 3*c*, then lie on straight lines drawn through the graduations on the (linear) scale of the radius of 90° and at right angles to the latter. Such a diagram is easily laid out by selecting a point as origin on millimeter paper, and drawing radii at intervals of 15° from this point. The divisions on the paper are numbered serially from the origin, and temperatures plotted on all radii in accordance with the same numbering. Of course, this form of diagram cannot be used for any series which does not become zero at 0° and 180°. The plot of temperature differences, in figure 3*c*, includes amplitude measured by the radius of the closed curve, and "form and attitude," graphically measured by the

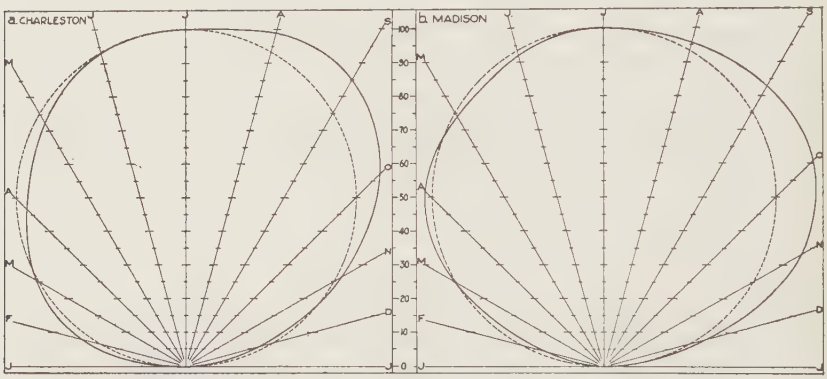


Fig. 5.

departure of the curve from the circle formed by the sine series. Madison, having the greater range, is represented by the larger curve. Mean height on the temperature scale is eliminated.

Amplitude may be eliminated as well, so as to leave for comparison only the "form and attitude" of the curve, by using, instead of the differences of table 2, the "month-factors" of table 3. The scale will then extend from zero to a maximum value of 100 at 90°. In figure 5 these are plotted for Charleston and Madison. It is not the purpose of this paper to discuss regional contrasts which appear in the figures, but attention will be called briefly to the difference in the manner of recovery from midwinter cold between the coastal mesothermal station Charleston and the continental microthermal Madison. The snow cover in Madison delays the warming up in early spring, but rapid warming later makes April relatively warm, as compared with Charleston, where the same month is relatively cool. Moreover, it is to be noted in the figure how summer heat is sustained through August

in Charleston, while it falls off in Madison. The greatest excess of actual temperatures over the symmetrical march occurs in September at Charleston, at Madison in October.

These peculiarities are to be seen most clearly when plotted as in figure 5, where the other qualities of the temperature march have been eliminated, yet are plainly to be seen in diagrams of the type of figure 3*a*, which in addition depicts the more outstanding qualities. Because of the simplicity of construction and general applicability of the polar type of diagram with the exponential plotting of temperature, the manner in which the larger features of the temperature march are represented on it will be examined in some detail.

VI

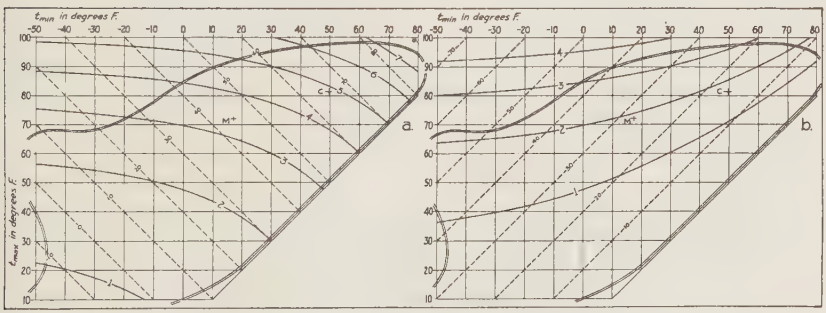


Fig. 6.

The general, mean value of the temperature through the year is of course represented by the mean radius of the nearly circular temperature curve. This is the actual radius in the circle formed (with the reservation noted above) by the sine series, in which the mean of the series is the same as the mean of the extremes. But because of the increase in the lengths of the intervals on the temperature scale at increasing distance from the pole of the figure, this radius does not increase directly as the temperature. This fact was seen above in the comparison of *a* and *b* of figure 4. In figure 6*a*, R is plotted (heavy full lines) on a field of rectangular coordinates representing the temperatures of the warmest and coldest months, in units of length such as were used in the exponential scale above. The double line encloses the field of variation of the temperatures of the entire earth. Within existing temperatures, the value of R varies between 1 and slightly over 7. For comparison, the means of the extreme temperatures,

$\frac{1}{2}$ $(t_{max} + t_{min})$, are plotted on the figure (dashed lines). R is an accurate measure of the mean temperature only where the differences between the extremes are minimal. In the cases of the two stations, Charleston and Madison, used throughout this paper, the lengths of R are very nearly proportional to the temperatures. The ratio of the values of $\frac{1}{2}$ $(t_{max} + t_{min})$ for the two stations is nearly 1:1.5, and the ratio of $\frac{1}{2}$ $(r_{max} + r_{min})$ is nearly the same. This is due to the fact that the curves for the two stations are nearly concentric, as is seen in figure 3*a*.

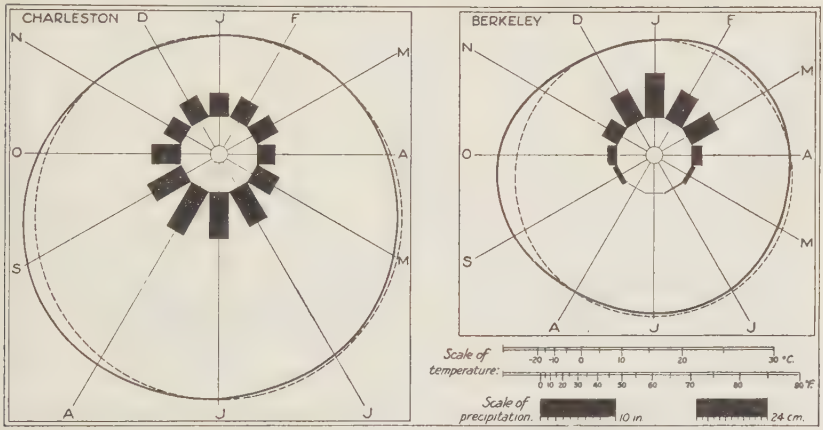
The graphic measure of the range in temperature between the warmest and coldest months is r', the radius vector of the center of the circular curve. In figure 6*b* the graphs of integral values of r' are plotted, and, for comparison, the graphs of $\frac{1}{2}$ $(t_{max} - t_{min})$. Within the temperature range of the earth, r' attains a length of three linear units in the hot dry climates. As in the case of R, r' is proportional to the actual range only where the range is small. Though Madison has a far larger range than Charleston, the value of r' for the two stations is nearly the same. In figure 3*a*, this is indicated by the nearly concentric relation of the closed curves.

VII

The above discussion has been concerned with temperature. But if a single diagram is to represent the climate of a place, it must also include a representation of at least precipitation in addition to temperature. Precipitation has, within a given climatic type, a characteristic annual march, and may be represented in polar form. The curve, however, is inappropriate as its graphic representation, since the measurement of precipitation is in terms of accumulating quantity rather than of fluctuating state.

In figure 7 graphs are shown which display temperature and precipitation for two types of mesothermal climates, *Cfa*, represented by Charleston, and *Csb*, by Berkeley (California). The temperature curves are plotted on the exponential scale. In the figure for Berkeley, the circle representing the sine series is drawn through the minimum point of the temperature curve (Jan.) and a point on the July radius having the same radius vector as the maximum, which here occurs in September. The peculiarities of Berkeley's temperature march appear distinctly: the warm early spring (Feb. and Mar.), the cool summer from April to August, and the warm autumn. In drawing the bars

representing precipitation, it is necessary to place their bases at some distance from the center. The zero of the graphs of precipitation is placed at the distance of one linear unit from the pole of the figure, at the same point as the zero of the F. temperature scale. The scale of the bars representing precipitation is made so as to include 45 in. (*ca* 114 cm). within the linear range of 10 units provided by 100 degrees on the temperature scale. The graduation of the precipitation scale is of course arbitrary. The polar form of graph articulates the seasonal precipitation, without dividing it into two parts, as occurs



a *b*

Fig. 7.

when Berkeley's rainfall, for example, is plotted on a rectangular diagram beginning with January and ending with December. The pattern of temperature curve and rainfall bars remains the same for the same type of climate, except that for stations in the southern hemisphere the entire pattern is rotated 180°. Each climatic type has its characteristic pattern.

VIII

Occasion may arise in which it is desirable to express a cumulative element, such as precipitation or evaporation, as a curve, as was done in the article by Munns cited above. Munns's method was to divide the month radii in accordance with a linear scale, lay out the appropriate distance from the center on each radius, and connect the points on the radii by lines enclosing a polygon, which was shaded. The graphic effect depends upon the area of the polygon, which, however, has no fixed relation to the amount of rainfall at the station. If the

area is to represent the rainfall accurately, the scale along the radii must be so graduated that it is proportional to the annual amount.

If the precipitation be assumed to vary continuously between the several months, a graduation of the sort desired may be arrived at by making each successive increment on the scale determine, between the circumferences described by its lower and upper terminal radii, an annulus equal to that determined by every other equal increment.

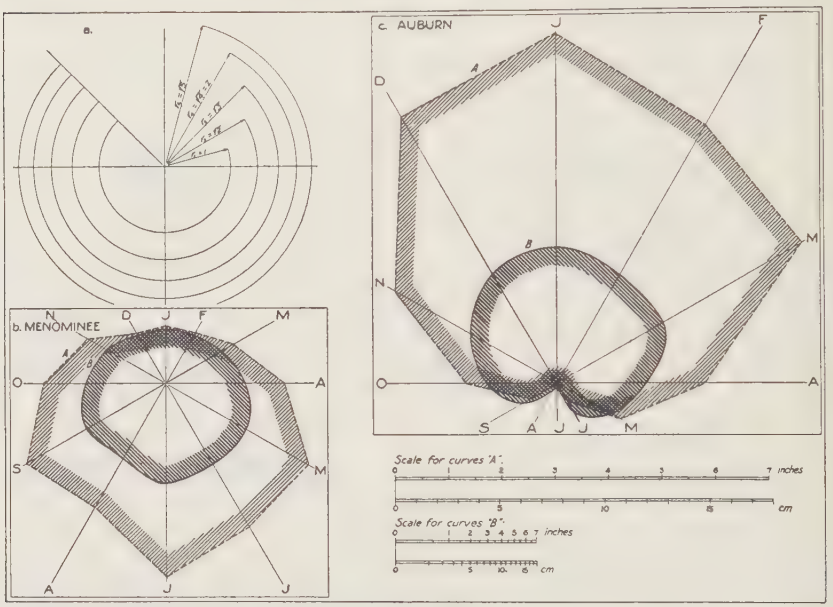


Fig. 8.

The annulus between two concentric circles of radii r_1 and r_2 has an area equal to

$$\pi\ r_2^2 - \pi\ r_1^2.$$

The innermost figure of a series of annuli is a circle; and if the radius of this circle is taken as r_1, the radius of the next circumference outward enclosing an annulus equal in area to the unit circle, r_2, may be found in terms of r_1 by equating the two areas:

$$\pi r_2^2 - \pi r_1^2 = \pi r_1^2;\ \text{then}$$
$$r_2 = r_1 \sqrt{2}.$$

Similarly, it may be shown that in a series such as is defined above, $r_1,\ r_2, r_3 \ldots\ldots r_n, r_n = r_1 \sqrt{n}$. If the pole of the figure be considered zero, and the unit circle have the radius 1, the successive radii

establishing the points on the graduation of the scale are $r_0 = 0$, $r_1 = 1$, $r_2 = \sqrt{2}$, $r_3 = \sqrt{3}$, and so on. (See fig. 7*a*.) "Equivalence," in the sense the term is used in the projection of maps, may thus be obtained in plotting a cumulative element on a polar diagram by plotting the square roots of the values for the several months, rather than the values directly. Again, the roots may be taken directly from a slide rule with sufficient accuracy for plotting.

In figure 8, *b* and *c*, the precipitation for two of the stations used as illustrations by Munns in the article cited is plotted. "*A*" in each diagram is plotted on a linear scale, as in Munns's figures, and in "*B*" of each figure the square roots of the precipitation values are plotted. In "*B*" the curves are smoothed by eye. The contrast between the two types of figure is less pronounced in the case of Menominee (Mich.), where there is less seasonal contrast in precipitation, than in Auburn (Calif.), where the rainfall is strictly seasonal. The total annual precipitation at Menominee is 26.86 in., at Auburn 33.75 in. The ratio between the two quantities is 1:1.26. Measurement by planimeter of the areas of "*A*" in figure 8, *a* and *b*, gave a ratio of 1:2.25; the ratio between the areas of "*B*" in the figure is correct to the second decimal place. In case precipitation is to be represented by a closed curve on a polar figure, the far more accurate graphic effect of plotting the square roots of the primary data abundantly repays the small effort required in reading the roots from a slide rule.

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LOWER CALIFORNIAN STUDIES

II. THE RUSSIAN COLONY OF GUADALUPE VALLEY

BY

OSCAR SCHMIEDER

Guadalupe Valley, about fifty miles south of the American-Mexican frontier, presents a minor geographic unit of distinctive cultural alteration. Guadalupe Valley is the only rural part of Lower California, the majority of whose population is, at the present time, composed of European immigrants. The Russian colonists, who form by far the most numerous element of the population of the valley, exert so marked an influence upon the cultural aspect of the landscape as to arouse even the attention of a superficial observer. Interaction between man and his habitat has produced here a unique result, a minor cultural landscape of striking individuality, which invites genetic analysis. In addition, this first attempt of collective colonization by European peasants in Lower California has the importance of a significant experiment.[1]

THE NATURAL SCENE

The valley of the Rio Guadalupe is in its central part a large, apparently structural depression of a type common to the granite highlands of southern California and northern Lower California. The basin ranges from two to eight kilometers in width, and is approximately twenty kilometers in length. The bottom of this depression lies between three and five hundred meters above sea level. The surrounding mountains are several hundred feet higher, culminating

[1] The observations on which the paper is based were made in December, 1927.

to the south in the Cerro de Guadalupe (4432 feet). It is with the widened, central part of the Guadalupe Valley, in the narrower sense, that this report is concerned (fig. 1).

The basin of Guadalupe Valley lies entirely within a zone of granite. The "woolsack" forms of weathered granite are ubiquitous on the slopes of the mountains which surround the depression. The valley bottom is entirely covered with recent alluvium, the surface of which slopes gently from the foot of the bordering mountains to the

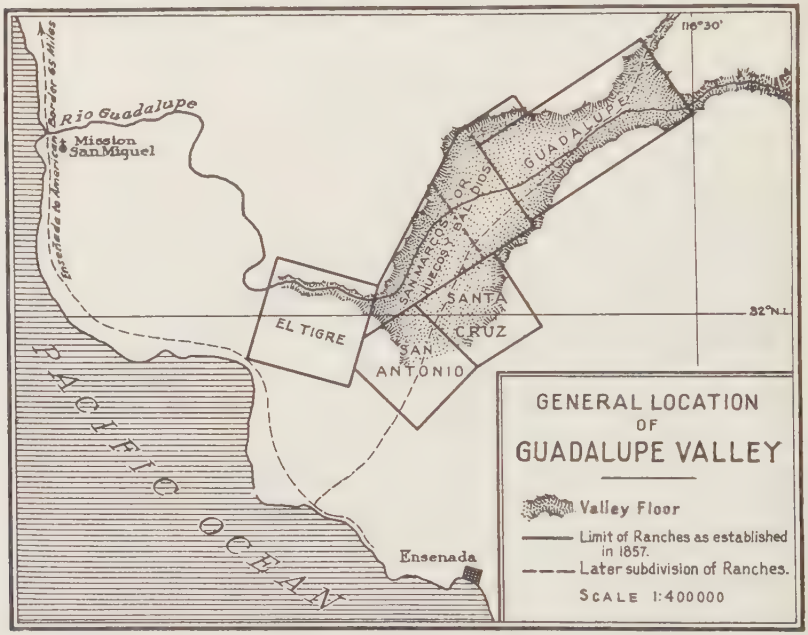

Fig. 1

central part of the depression (pl. 35). The entire valley fill is evidently derived from the surrounding granite mountains, showing, however, a marked zonal differentiation. Coarse material, stones, and boulders are inconspicuous. Surrounding the valley is an outer belt of red clayey loam, superimposed on, and partly weathered *in situ* from the granite. This red covering is being washed down by surface water toward the central part of the valley. With increasing distance from the mountains the soil becomes sandier, and changes its color. The inner valley floor on both sides of the river bed consists of a more recent dark gray, very sandy loam; the wide river bed, finally, is filled by sand. (See map.)

The Rio Guadalupe passes through the valley in its entire length, and receives a number of minor streams from the bordering mountains. The whole hydrography shows the features which are imposed by a climate with rainfall concentrated into a few months. At the end of December, 1927, after the first light rainfall, the main river bed was entirely dry for long distances. After heavy rains, however (and rainfall of three inches in twenty-four hours has been known), a flood may inundate large parts of the valley, occasioned in part by rapid drainage from the mountains to the east. Since the surface water is an occasional hazard and of little advantage, no provision is made for storage, the economic interest being concentrated on underground water.

Ground-water conditions in Guadalupe Valley are particularly favorable. Excellent and abundant water is to be found in the stream bed at a depth of three to four meters. In several places the water table appears at the surface. The permanent ponds, *ojos de agua* and *lagunas*, mostly located in abandoned stream beds on the bottom of the high water bed, are not remainders of the last high flood. They are fed directly from the water table, which forms numerous freely flowing wells all around the ponds. The abundant supply of ground water easily obtainable in all parts of the valley, is an important asset.

The meteorological observations available for Guadalupe Valley[2] are not sufficient to support a definite classification of the climate. The basin cannot, apparently, be said to be located well within the B climates.[3] For the year beginning September, 1921, and ending August, 1922, the total rainfall in the valley was 21.93 inches; from September, 1922 to August, 1923—13.37 inches, and from May, 1926 to April, 1927—19.8 inches. These annual precipitations are undoubtedly much above the average. Yet they suggest that Guadalupe lies near the border between the BS and C climate. Other observations support this assumption; e.g., the type of land cultivation: wheat-growing based on rainfall; also, the growth of well developed live oak and other trees.

Rain occurs almost exclusively during the winter. Midsummer is mostly dry. The beginning of the rainy period is subject to a

[2] Mr. Barré, an American engineer who settled, in the eighties, in Guadalupe Valley, has carried on meteorological observations since 1921. Since 1923 the observations on rainfall have been published in the Boletin Mensual, Servicio Meterológico Mexicano.

[3] Symbols are those used by Köppen, W., Die Klimate der Erde (Berlin, 1923).

periodic change. October may bring the first heavy rains, but they may also occur as late as January. The end of the rainy season comes from March to May.

The Mexican records contain no data on temperature; only the occurrence of frost is recorded. Frost occurs every winter, but only on a few nights.

The vegetation of Guadalupe Valley has been changed fundamentally by man, since almost the entire valley bottom has been put under cultivation. Some isolated live oaks indicate, perhaps, that this tree originally formed groves on the older valley bottom. Even now there still exists one live-oak grove in the *Rincón de los encinos* (see map), but in the eighties of the past century similar groves occurred as far as the western border of the Rancho Ex-Mission Guadalupe.[4] It is evident that general climatic conditions favor the growth of live oaks, and that they do not depend on local conditions, such as a high water table. That man is responsible for the present sporadic distribution of this tree seems very probable. The recent establishment by the government of a heavy fine for the cutting of live oaks is suggestive, and is evidently proving effective.

Along the river bed extends a narrow belt of poor gallery forest (pl. 35). Deciduous bushes prevail, exceeded only by a few taller trees, mostly cottonwood. The periodically repeated floods evidently deter growth.

The abandoned river beds, especially where the ground water comes to the surface, are covered with high and dense reeds (pl. 36*a*). A regular reed thicket surrounds, e.g., the Laguna Barré, forming a hiding place for numerous wild ducks and other birds.

CULTURAL SUCCESSIONS OF THE PAST

The aboriginal population of the Guadalupe Valley has been entirely replaced by later comers. The older settlers still remember their last huts at the Rincón de los encinos (see map). It almost appears as if Indian and live oak vanished together from the scene, the last Indians gathering under the last remaining live oaks. From the Rincón de los encinos (live-oak corner) they used to undertake their annual migration to the coast, where they caught fish and collected clams.

[4] Information given by Mr. Barré.

The Mission established in the thirties of the past century did not displace the Indians; on the contrary it provided them with new means of sustenance, introducing agriculture and developing their cattle-raising.

The third period in the cultural succession of Guadalupe Valley started with the secularization of the Mission. In 1858 the Mexican Government, ignoring the rights of the old aboriginal population, sold the *terrenos baldíos,* "the unoccupied" land. The valley and the surrounding mountains were thus divided into several large ranches: Ex-Mission Guadalupe (13,014 acres), San Marcos or Huecos y Baldíos (12,355 acres), Santa Cruz (6,177 acres), San Antonio (6,177 acres), and El Tigre (8,676 acres).

Whereas the Mission had been, at least theoretically, established in the interest of the Indians, the newly established private landed proprietors looked first to their own interest. The Indian became dependent on the Mexican landowner, and his only chance to make a living was by working as a cowman or farm hand. Stock-raising and casual wheat-growing were carried on. The huts of the Indians still remained in the valley; a few houses of rancheros, surrounded by gardens, appeared on the scene.

It was left to the last, in the cultural succession, to eliminate the Indian. The European peasants who arrived at the beginning of this century did what the Mexican ranchero had never thought of doing; they, themselves, worked the soil, and no room was left for the Indian who had a traditional right but no legal claim to the land. He had to leave the valley and retire into the mountains. In the small valleys, all around Guadalupe, where there are only small patches of arable land, too insignificant to attract the white man, scattered aboriginal families are still to be found. A fair wagon road leads to the Indian settlement. This road was built by these few Indians themselves, and on their own initiative. Moreover, the aspect of the neatly thatched huts (pl. 36*b*) and small fields by no means suggests that these Indians are of such a poor type as the Mexicans and Russians like to paint them. Driven from their fertile, native valley they have certainly put forth a remarkable effort to make a living in the poor and rough mountains.

A satisfactory genetic analysis of the present-day cultural landscape will have to establish as clearly as possible a distinction between old cultural features imported from the native country of the colonists, and cultural elements acquired by the colonists under the influence of the new environment.

EXTRACTION OF THE COLONISTS

In the course of the nineteenth century, Russia advanced her borderline beyond the Caucasus, penetrating even into the Armenian highlands. The latest addition to the empire was the area around Kars (1878). The native population of this country refused to be displaced, but a considerable number of Great-Russians settled among them. Among the Russians who were compelled to settle at Kars were the parents and some of the elder present colonists of Guadalupe. They were linguistically Great-Russians, yet ranked in the eyes of the government as an undesirable element, since they did not profess the true belief of the Great-Russian, the Greek-orthodox religion. They were Molokanye,[5] sectarians closely resembling the Scotch-Presbyterians. The fact alone that they had given up the utterly dogmatic Greek religion presupposes a certain critical and progressive attitude. And indeed, being "of the same race and placed in the same economic conditions as the Orthodox peasantry around, they were undoubtedly better housed, better clad, more punctual in the payments of their taxes and, in a word, more prosperous."[6] Their whole material culture, however, was essentially the typical one of the southern Russian peasant.

For a quarter of a century these compulsory Russian colonists lived near Kars in an absolutely strange cultural milieu. Yet they preserved their habits, religion, and social structure unchanged. Transformed from the southern Russian plains to the mountains, they never became well rooted in their new environment. The older men at Guadalupe still speak with horror of the cold winters of the Armenian highland.

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[5] D. M. Wallace, Russia (revised ed., 1912), chap. 17, gives a good account of this sect. They condemn image worship, fasting, episcopacy, and accept the Bible as the only rule of faith. Their religious services are held in private houses, the pastor being an uneducated peasant like the others. They refuse military service. Birth, marriage, and death are considered family affairs, no interference of public authorities being tolerated. They maintain these religious prescriptions up to now, in spite of the fact that they have frequently annoying consequences; e.g., when a young "Russian" born on Mexican territory desires to enter the United States as Mexican non quota emigrant, and is not eligible for admission, since his birth has never been registered.

[6] Wallace, *op. cit.*, p. 258.

EMIGRATION AND COLONIZATION AT GUADALUPE

Because of the economic difficulties of the years preceding the Russian revolution of 1905, and the insistence of the Russian government on military service, they resolved to emigrate. In 1904 they began to leave their country. Their emigration was not favored by the Russian government; on the contrary, it was officially opposed. In small groups, "like coyotes" to use the term of one of them, they left their country.

Their emigration had no definite goal. The different families of their community spread over the western hemisphere. I found colonists who had gone first to the Argentine, to New York, and to California. Most of them, however, went first to Canada since they knew that thousands of *Dukhobors,* sectarians similar to the Molokanye and frequently called the Russian Quakers, had found a new home there.

Their stay did not last very long in any of these places. Through their ancient inherited system of mutual assistance and control the widespread groups were kept in contact. "Canada has a climate like Kars, we wanted a climate like Tiflis. That is why we all joined our people who had gone to southern California."

They had no objection to the climate of southern California but neither did this country entirely satisfy them. The "one acre and economic independence" system of southern California, which involves high land prices and most intensive soil cultivation, could have little attraction to a Russian *Muzhik.* The characteristic land hunger of a Russian peasant could not be satisfied in southern California. What they wanted were large tracts of land, which they could cultivate in the traditional way.

Thus, the logical thing for them to do was to look beyond the borderline to Mexico. They thought that Lower California would better meet their wants. Climatic conditions in the northern part of the peninsula are similar to those of southern California, yet the area is not inhabited by a population which would oblige them to adopt a more efficient type of agriculture than that to which they had been accustomed in Russia.

Establishment of the Colony

The system of primitive cooperation carried on through many generations was so ingrained that the idea of individual colonization did not occur to them. They acquired in community the ranch, Ex-Mission Guadalupe, with thirteen thousand acres, of which approximately six thousand acres are arable land. The price agreed upon was $50,000 in American money. Upon an initial payment of $5,000, the ranch was turned over to them in 1905. Since the original group of colonists consisted of one hundred families, the average contribution of each was $50. As long as any debt remained, every farmer turned over half of his crops to the community. At present the land is free from mortgage.

The mentality of the colonists, which is essentially conservative and almost fanatically traditional, was a guaranty for the preservation of a maximum of old cultural goods in the new environment. Particular juristic notions to which they had been accustomed through many generations proved strong enough to determine the type of settlement which, eventually, became established. That land does not belong to the individual but to the parish, has been, through three centuries at least, a matter of course with the larger part of the Russian peasantry. This *Mir*[7] system, also, was, for the group of Russian emigrants under consideration, a notion inseparable from peasant land tenure.

The land was divided into small lots and these were distributed among the different families. The fields which each family received were not contiguous; the leading viewpoint being that each family ought to have an equal amount of good and bad land. No colonist received an individual title to his land. His rights were based on simple mutual agreement. Even the individual usufruction of the arable land is restricted. After the gathering of the harvest all fields become common pasture. From April until December the whole extent of the colony is considered parish property and every part of it is open to the grazing stock of any colonist. When a family retired from the colony, it sold or rented its field to one or several

[7] The existence of the *Mir* dates back, at least, to 1500. Yet it was such a matter of course with the Russians that only at the middle of the nineteenth century was it scientifically announced by Freiherr August von Haxthausen through his work: Studien über die innern Zustände, das Volksleben und insbesondere die ländlichen Einrichtungen Russlands (3 vols., 1847–52). Since then abundant literature on the subject has appeared.

colonists, leaving to the community a document in which they resigned their rights as members of the colony.

Simplification of tax collection by making the village Elder (*Starosta*) responsible for the totality of the taxpayers had been, indeed, one of the main reasons why parish property has been introduced and continued in Russia.[8] In Mexico the authorities did not favor the system. Yet the stubbornness of the colonists has, up to now, not yielded to any pressure.

Type of Settlement

The old Russian notion of the land being community property, with its lack of individual land titles, precluded, of course, the isolated farmstead as the type of settlement and brought about the foundation of a closed settlement; a village. The founding of one large village in Guadalupe Valley is indeed contrary to any practical consideration and is to be explained only by the existence of an old inherited juristic notion, too deeply rooted in the minds of those peasants to yield before any environmental influence. Distances from the fields are largely such that the men are unable to return to their homes in the evening, but camp often for weeks on their lots. Inconvenient conditions, such as are typical for southern Russia, are thus repeated where they could easily be avoided.

When the Russian peasants took over Guadalupe, there were but three houses on the ranch. These houses, however, did not become nuclei around which other dwellings were built. Only one of them, the one which stood right near the ruins of the old Mission, remained in use as a schoolhouse. The other two were allowed to decay while the colonists laid out their village independently of any existing settlement, and did so in a typically Russian way. The dwellings, barns, and other buildings are lined up along a single, broad street (pl. 37). High trees shade the road and add to the Slavic aspect of the village, in spite of the fact that most of them are eucalypti and pepper trees.

Not only the general plan of the settlement is that of a Slavic *Strassendorf;* the house type, too, reveals the extraction of the settlers. Adobe and quarry stone form the prevailing building material in southern Russia. The colonists found the local granite too hard to be used; they chose the familiar adobe.

[8] Responsibility of the Starosta for the obligations of all members of the community was not abolished until 1903.

The houses are roofed with large shingles, such as are used in their native country (pl. 37). The small shingles are, as they themselves declare, an improvement which they learned in the United States. Reed and grass, which the Indians use for thatching (pl. 36*b*) are nowhere used by the Russian, who prefers to buy imported American redwood for his shingles. Not only the roof, but also the gable wall, frequently turned toward the street, is covered with wood, another Russian feature (pl. 37*b*).

The prevailing arrangement of the rooms is typically old Russian, originating in the log houses of the northern forests, and later transplanted with the southward advance of colonization into the adobe houses of the treeless steppe. Two main rooms are separated by a minor, central room through which one enters the house.

The furniture is modest and almost entirely of American manufacture. But sufficient details give to the interior of every home a decidedly Russian character. The great shining brass samovar is in daily use in every family, and forms apparently, next to a big Bible, the only valuable part of the outfits with which these peasants left their country. The mild climate of the valley has not yet overcome the Russian antipathy against open windows. Where a window glass is broken, the women will anxiously keep out the fresh air by putting into the opening a rag, a coat, or whatever is most handy. The typical smell of insufficiently cleaned feather quilts, piled up on the beds, is thus well retained and completes the impression of a true Russian peasant home.

Each house has its big brick oven, and, in a separate little building, the old Russian bathroom, where a good fire heats up a pile of big stones. By pouring water over them, the room is filled with steam, in which the whole family religiously takes its Saturday evening bath. Even the men who camp on distant fields do not fail to be back for the week-end bath.

SLIGHT MODIFICATIONS OF MATERIAL CULTURE

Twenty-seven years in a largely oriental milieu at Kars, and twenty-two years in a Latin American country, have had but scant influence upon the material culture of the colonists, whereas their short acquaintance with American culture has left visible traces. Every household is still to a large extent self-sufficient, as in a rural district of Russia. There is no economic specialization in the colony;

every colonist is his own butcher, baker, blacksmith, harness-maker, etc. The only mechanician is a Mexican who repairs their motors and automobiles. Yet the acquaintance with American manufactured articles has caused the loss of a considerable part of their former handicraft. The women do no more weaving and spinning. They have become "flojas como Indias," lazy as an Indian squaw, as an old colonist put it. American overalls, coats, hats, boots, etc., have replaced the homemade cloth (pl. 39*a*). They have also learned the advantages of using modern agricultural machinery, and every colonist has at least his American-made plough, sowing machine, and thrashing machine.

TYPE OF AGRICULTURE AND ITS INFLUENCE ON THE LANDSCAPE

The use of modern agricultural machinery by no means implies, however, an improvement of their old agricultural methods. Rather they became still more extensive.

They had, also, to change their traditional means of traction: the oxen. The old colonists are still discussing the reason why the Mexican oxen cannot be used before the plough. Back in southern Russia, the oxen were so tame that nobody thought of using horses. They could not agree whether it was that they could not find the right breed in Lower California, or whether the reason lay in the fact that their Russian cattle were tame due to the long enclosure in stables during the rigorous winters, whereas the Mexican cattle were unfit for team work since they permanently roamed around in full liberty. Anyway, they all had taken to the horse as the beast of draught.

For the rest, their type of agriculture is still the same primitive and extensive one which has brought famine so frequently to the rural population of the most fertile parts of Russia. They cultivate an extensive surface and do not restrict themselves to the land they own. Their influence on the landscape therefore exceeds by far the limits of the old Rancho Guadalupe. Wherever there is arable land in the neighborhood, the Russian will rent it from the Mexicans, who use it only for stock-raising. Since natural vegetation forms no obstacle to cultivation, the rented land needs simply the plough. Contracts, therefore, are made only for one year and the tenant frequently

changes. Even many miles away from their village they will pitch their tents and camp as long as the work on the fields requires their presence (pl. 39*b*). The system pleases the Mexican landowners, who receive one-fifth of the crop without exerting any effort on their part. Since the Russians are the only inhabitants there who profess such land hunger, they have no difficulty in getting as much land as they can cultivate. The way in which they select the land seems to be absolutely unmethodical. I have heard them call, casually, to passing Mexicans, and ask them if, by the way, they had any land to rent.

It is this fact alone, that arable land for rent is easily obtainable in the neighborhood, that has made it possible for them still to carry on their agriculture in the old primitive way. Restricted to the land which they own, they would long ago have exhausted the soil. Their ploughs overturn only the barest surface of the soil, and hardly remove the weeds. No kind of fertilizer is used, save the manure of cattle and horses, which is spread over the stubble fields when used for pasturage. This gives the only advantage they have over south Russian conditions, where the manure is burned, for lack of other fuel. Rotation of crops is absolutely unknown. For over twenty years wheat has been their only market crop. Only when completely exhausted, is the soil left to fallow for a year or two.

By reckless and primitive methods the yield has been considerably decreased. I learned from a reliable source that on the best wheat land of the valley, in the Cañada del Trigo, the yield of an acre has decreased from sixty bushels about twenty years ago to some fifteen bushels at present. The system is certainly dangerous, but as long as the deficit of their own land can be made up on rented land, the Russians will hardly change their methods. The crop of a normal year brought in by some fifty or sixty families is about 125,000 bushels, but in bad years the crop is reduced to one-third of this amount.

Agriculture carried on in this way makes the life of the colonists rather agreeable. In December, with the beginning of the rainy period, ploughing and sowing begin. They like to begin with the light soils of the inner valley and leave the heavier soil until after the first rains. The crops are harvested in April. The aridity of the summer makes a second crop impossible. From May to December the activities of the colonists become restricted to the work at home preparation of the wheat for the market and cultivation of their gardens and orchards.

The orchards of the colonists prove that they have learned something, at least, since they left the rough highland of Armenia. Their stay in southern California has been responsible for this attainment. Actually, every farmhouse has its orchard irrigated from a well by means of a windmill. Oranges, peaches, vegetables, etc., are grown, but only for home consumption. They were especially proud that they had learned to cultivate grapes. Their vineyards are indeed expanding and two of the colonists have been bold enough to prepare wine. It is suggestive that one of the two came, not from Kars, but from Tiflis.

On the other hand, their beehives and their flocks of geese are peculiar to them, and are not to be found in any of the Mexican settlements.

Their livestock is relatively important, yet not a direct source of income. The number of cattle which every family owns ranges from ten to three hundred. Besides this, each farmer has the horses which he needs for his field work. Breeding is carried on quite carelessly. Natural pasturage and partly unthrashed wheat straw is the main feed. No improved pasture exists. A single attempt to plant alfalfa ended in failure and has not been repeated.

The mountains surrounding Guadalupe Valley ought to be, one should say, an excellent place to raise goats and sheep, yet no advantage is taken of them. Coyotes are numerous around Guadalupe, and are blamed for the failure to raise sheep or goats.

DEVELOPMENT OF THE COLONIA RUSA

The original group of Russians who settled at Guadalupe consisted of about one hundred families. According to inquiries the number of children ranges from eight to thirteen in each family. One might suspect, therefore, a rapid expansion of the Russian element, since they were successful in acquiring a considerable amount of land, and would find no difficulty in purchasing more. Yet the contrary is true. In spite of the prosperity of the colony, the rapid multiplication and excellent health conditions, the population decreases.

The cause of this rather astonishing fact lies essentially in the near neighborhood of the United States. If it were not for the American immigration law the decrease would probably be more drastic. Under the present conditions only those who are younger than 25

years, that is, those born in the new world, are able to cross the frontier. And, indeed, the fact is striking that middle-aged men and children are most numerous in the colony. There are still 330 inhabitants at Guadalupe, of whom 110 are schoolchildren between 6 and 12 years. There was not only one large emigration of entire families to the United States in 1912, but the young men and girls, once independent of the family, invariably go beyond the borderline. It is evident that the vicinity of the prosperous United States, and the fact that the frontier is open to people born in Mexico, checks the expansion of the Russian influence. In spite of their natural fertility, they will not be able to impose their culture on a larger area than Guadalupe Valley itself.

CULTURAL ALTERATION OF THE YOUNGER GENERATION

The Mexican government is making an effort to assimilate the Russians culturally. Besides a Federal delegate, it maintains four schoolteachers at Guadalupe, whose influence on the younger generation is evident. There is no doubt that the mental as well as the material culture of the inhabitants of Guadalupe will become quite different when the more conservative older generation has disappeared. What actually will become of them is hard to predict, since the experiment is still under way, and the situation is complicated.

At present the whole colony is still in the hands of those men who were born and raised in Russia. The children pass their first years in the exclusively Russian milieu. The father is a conservative Russian peasant with undisputed authority as head of the family. The mother has not even learned a word of Spanish. At the age of six they pass, for another six years, under the influence of the school. There the teaching is carried on in Spanish; and the Mexican schoolteachers manifestly attempt to modify their mentality and to break down the influence of the family. But at the age of twelve, the influence of the school ceases. The children go back once more under the influence of their parents, whom they help at home and in the fields. But, once grown up, they desire independence and go, at least temporarily, to the United States. Every young man talks broken English.

Three essentially different cultures are thus acting upon them. The final result of such a complex environmental influence on a rather primitive group of people is still problematic.

EXPLANATION OF PLATES

PLATE 35

a. View across Guadalupe Valley from the south. Granite mountains in the background. Along their foot extends a belt of yellow, clayish soil, varying in width, and sloping gently toward the inner valley; here are the most fertile fields of the Russian colonists. The village, about two kilometers in length, runs parallel to the low bluff that marks the border of the high water bed. The old Mission was located on a little isolated hill with a granitic foundation.

Cañada del trigo

Site of old mission

PLATE 36

a. Laguna Barré. An abandoned stream bed cut in below the surface of the water table. The pond is fed by ground water and is therefore permanent.

b. Ranch of an Indian family at Aguas Escondidas, north of Guadalupe Valley. It represents the oldest type of dwelling in the area. The technique is that of the aboriginals, the form has presumably been modified under the influence of the missionaries.

a

b

PLATE 37

a. Casa de las Palmas. Remains of adobe walls indicate the site where the first Mexican landed proprietor in Guadalupe Valley had his house. Three palm trees are all that is left of the garden and orchard which once extended down to the river.

b. Typical Russian colonists of Guadalupe. Woman's dress has suffered no modification. The men wear American clothes; the only article from the old country is the cap of the man in the center.

a

b

PLATE 38

a and *b*. Main street of Guadalupe. The settlement has all the characteristic features of a typical Slavic *Strassendorf:* the wide street bordered with trees, the houses either with the front or the gable toward the street.

a

b

PLATE 39

a and *b*. Farmyards of Russian colonists at Guadalupe. The buildings are made in true south Russian style. The farm implements are American-made. Heavy feather beds are being sunned.

a

b

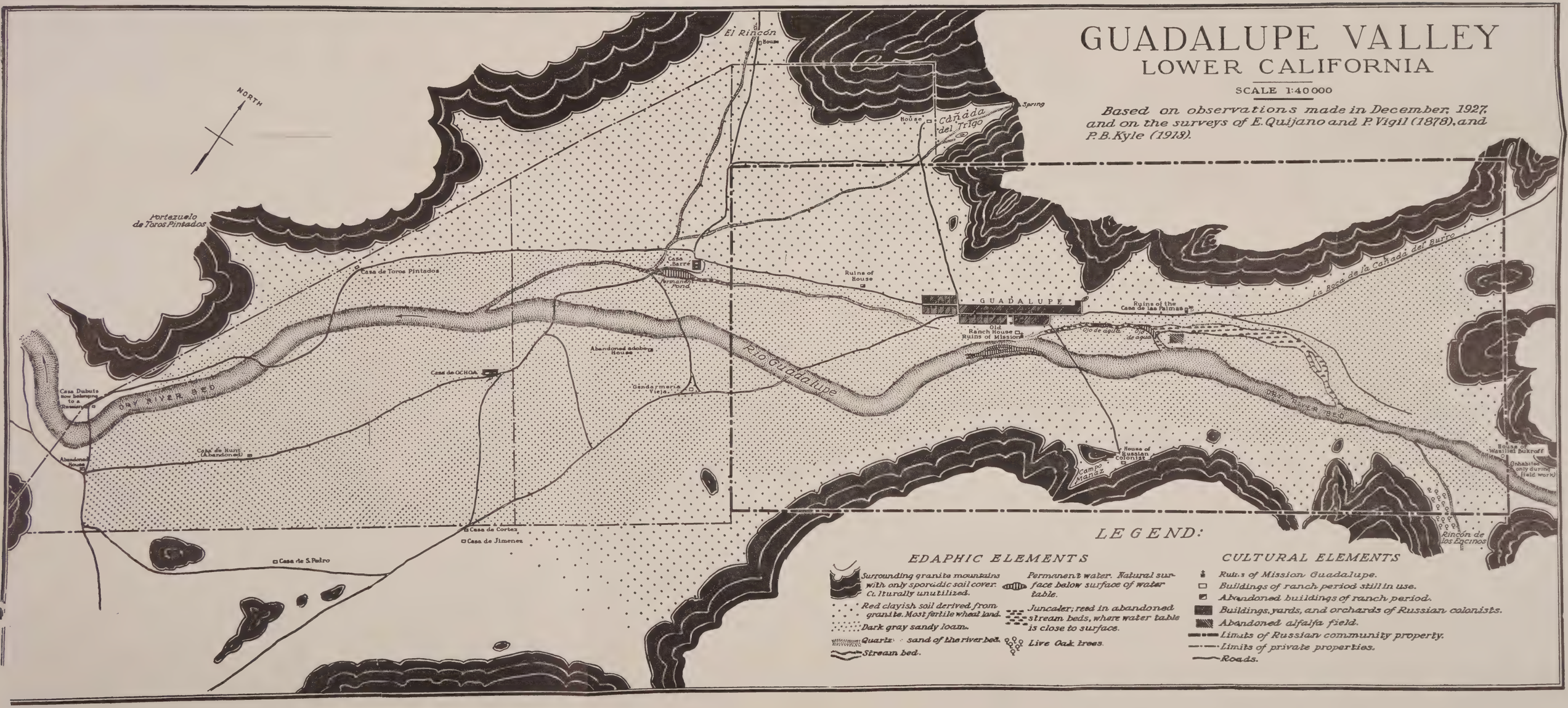
PLATE 40

a. Camp of the Russian colonists under the live oaks at Rincón de las Encinos. The fields are so far away from the village that the men have to camp for weeks during the periods of field work.

b. A Russian ploughing at Guadalupe. Draught horses are substituted for oxen. Only the uppermost part of the soil is turned, even the weeds are not ploughed under.

a

b


GUADALUPE VALLEY
LOWER CALIFORNIA
SCALE 1:40000
Based on observations made in December, 1927, and on the surveys of E. Quijano and P. Vigil (1878), and P. B. Kyle (1918).
NORTH
El Rincón
House
Cañada del Trigo
Spring
Portezuelo de Toros Pintados
Casa de Toros Pintados
Casa Barré
Permanent Pond
Ruins of House
GUADALUPE
Ruins of the Casa de las Palmas
La Boca de la Cañada del Burro
Old Ranch House Ruins of Mission
Ojo de agua
Río Guadalupe
DRY RIVER BED
Abandoned adobe House
Casa de OCHOA
Gendarmería Vieja
Casa Dubuis now belonging to a Dressery
Casa de Hunt (Abandoned)
Abandoned House
Casa de Cortez
Casa de Jimenez
Casa de S. Pedro
House of Russian Colonist
Campo Manaz
House of Wassilief Bukroff
(Unhabited only during field work)
Rincón de los Encinos
LEGEND:
EDAPHIC ELEMENTS
Surrounding granite mountains with only sporadic soil cover. Culturally unutilized.
Red clayish soil derived from granite. Most fertile wheat land.
Dark gray sandy loam.
Quartz sand of the river bed.
Stream bed.
Permanent water. Natural surface below surface of water table.
Juncales; reed in abandoned stream beds, where water table is close to surface.
Live Oak trees.
CULTURAL ELEMENTS
Ruins of Mission Guadalupe.
Buildings of ranch period still in use.
Abandoned buildings of ranch period.
Buildings, yards, and orchards of Russian colonists.
Abandoned alfalfa field.
Limits of Russian community property.
Limits of private properties.
Roads.

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ERRATA

Page 55, line 13. *For* controlled *read* uncontrolled.

Page 63, line 10. Footnote reference *10* should follow *season,* line 20.

Page 65, line 16. Omit *tropical* before *stations.*